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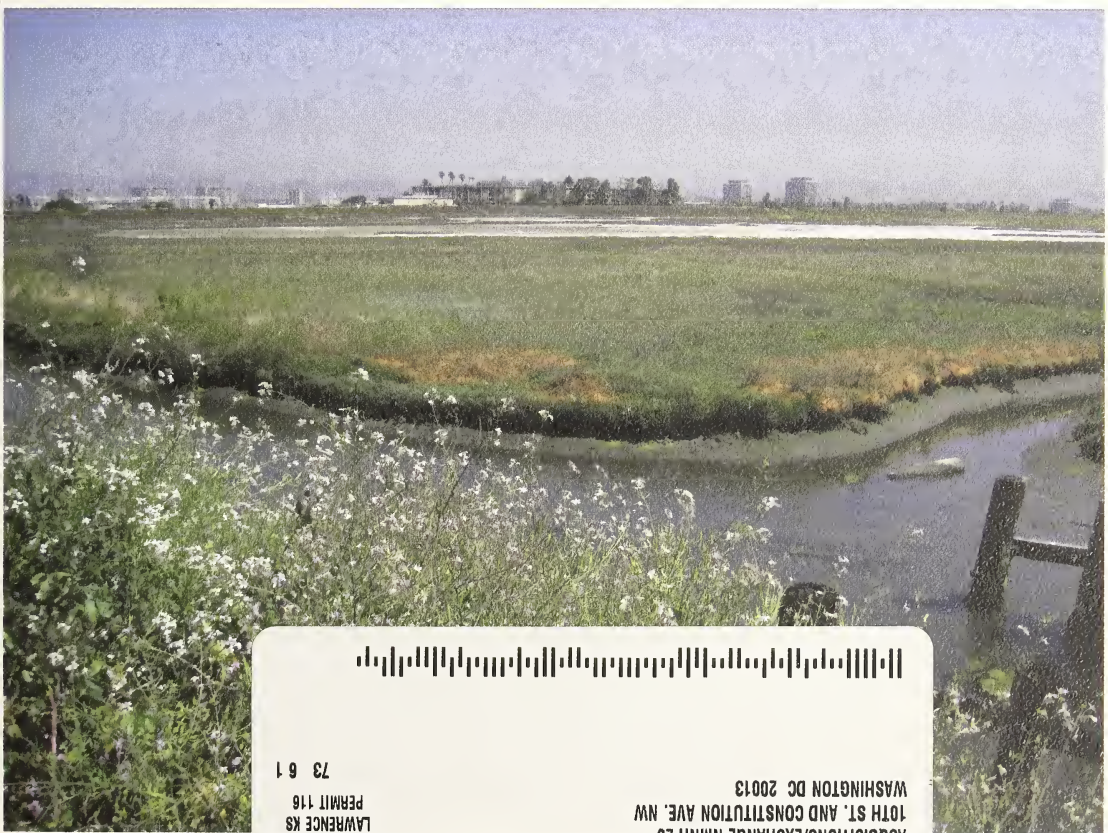

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The Physical Characteristics of Nearshore Rocky Reefs in The Southern California Bight

Daniel J. Pondella, II,[1]* Jonathan Williams,[1] Jeremy Claisse,[1,2] Becky Schaffner[3]
Kerry Ritter[3] and Ken Schiff[3]

[1]*Vantuna Research Group, Occidental College, 1600 Campus Rd., Los Angeles, CA 90041*
[2]*current address: Biological Sciences Department, California State Polytechnic University, Pomona, CA 91786*
[3]*SCCWRP, 3535 Harbor Blvd., Suite 110, Costa Mesa, CA 92626*

Abstract.—We present a GIS method for mapping and characterizing nearshore reef habitats. Utilizing this technique, we were able to successfully map all nearshore (<30 m depth) rocky reefs in the Southern California Bight and then quickly assess and characterize these data layers with expert opinion. The southern California coastline is 1198 km in length, with the eight Channel Islands and mainland comprising 503 km and 695 km of coastline, respectively. This is approximately the same amount of coastline as the rest of California. Within this region, we identified and characterized 122 natural reefs comprising 49,055 hectares, which is 26.6% of the 184,439 ha of nearshore habitat in the bight, the remainder comprised of soft bottom. Reefs varied appreciably in size ranging from 6 – 2498 ha. We sampled a subset of these reefs using a generalized random tessellation stratified design and quantified their physical characteristics as measured by scuba surveys. The reefs also varied with respect to habitat type and five distinct sub-habitat types varying from sheer oceanic pinnacle reefs to low-lying cobble were observed. The distribution of reef types varied between the mainland and islands. Island reefs were, in general, higher relief and had a greater percentage of rocky substrate. Mainland reefs generally had lower relief and a higher percentage of sand and cobble substrates.

The Southern California Bight (SCB) is a unique and increasingly critical stretch of the California coastline. The physical constitution of the coastline along the mainland SCB is primarily picturesque sandy beaches, broken up by rocky-headlands. In contrast, the remainder of the state is dominated by iconic palisades associated with the coastal uplift from the shearing of the right-lateral strike slip-transform San Andreas fault system (Zoback et al. 1987). Similar and associated strike-slip faults and resulting uplift are the origins of the major coastal headlands in the SCB that are broken up by sandy beaches (Emery 1960). The San Andreas fault system that runs along the coast in central and northern California moves inland proximate to Point Conception the upper limit of the bight. The SCB is floored by a ~300 km wide region of extensively faulted and extended continental crust comprising Mesozoic metamorphic and intrusive igneous rock as well as Neogene sedimentary and volcanic units (Crouch and Suppe 1993). This region of submerged continental crust is referred to in the geological literature as the California Continental Borderlands (CCB). It differs markedly from the continental shelf north of Point Conception, which is typically less than 100 km wide. The northern end of the CCB is formed by the east-west oriented Transverse Ranges, a large fault-bounded crustal block that

* Corresponding author: pondella@oxy.edu

underwent 90° of clockwise rotation between 15 MYA and 5 MYA, the age of the SCB (Luyendyk 1991). The unique east-west transverse ranges of southern California extend through the CCB as the Northern Channel Islands (San Miguel, Santa Rosa, Santa Cruz and Anacapa) and, as such, these islands are comprised of metamorphic and igneous rock (Atwater 1998). Differential subsidence along the many faults that cut the CCB has produced the distinctive topography of islands separated by ~1 km deep basins. Rotation of the transverse range block and the submergence of extended continental crust in its wake created the SCB from a preexisting coastline that had relatively straight, NW-SE trend and continuous with central and northern California (Atwater 1998).

The Northern Channel Islands currently appear as extensions of the Santa Monica Mountains and were all connected at the last glacial maximum (Graham et al. 2003). The orientation of these islands is an indication of the torsion caused by the shear of the North American and Pacific Plates forming the SCB during the Miocene (Atwater 1989). The subsequent uplift of metamorphic rock from the Catalina Schist formed Catalina Island. Meanwhile, San Nicolas Island is primarily an eroding anticline comprised of sandstone and shale marked by characteristic marine terraces with some igneous rock (Kemnitzer 1933). In contrast, Santa Barbara Island juts imposingly out of the sea with vertical cliffs up to 150 m in height and is comprised of brittle igneous rock, which exhibits less pronounced marine terracing. Kemnitzer (1933) also noted that a rock sample he received from Begg Rock, an exposed pinnacle reef 8 km off the west end of San Nicolas Island was also volcanic. San Clemente Island lies on the San Clemente fault, is formed of volcanic rock and has an anticlinal structure and prominent marine terracing (Olmsted 1958). The origins of the various rocky reef habitats in the SCB are diverse and complex, with considerable spatial variability.

It was previously estimated that the amount of nearshore reef habitat (< 30 m depth) was proportional to the rocky intertidal habitat, approximately 15% of the mainland (Stephens et al. 2006). The southern California islands, however, support a greater proportion of coastal reefs versus soft substrate in the nearshore environment (Ebeling 1980, Pondella and Allen 2000). Due to accessibility and increasing stress by a growing population, these reefs are under a variety of anthropogenic stressors (e.g., turbidity, river plumes, sedimentation, overfishing and pollution) and subject to harmful algal blooms (Stull et al. 1987, Horner et al. 1997, Dojiri et al. 2003, Schiff 2003, Love 2006, Pondella 2009, Foster and Schiel 2010, Sikich and James 2010, Erisman et al. 2011), which in many instances are not well understood and in all cases necessitate a bight-wide perspective and coordination to contextualize and manage. These reefs have been impacted by sewage, habitat loss, runoff and climate change and, as such, can serve as a model for dealing with these complex anthropogenic interactions (North 1964, Steneck 2002, Ford and Meux 2010). It has been demonstrated that large-scale management actions can have significant positive effects on this complex ecosystem (Pondella and Allen 2008). In 2012, a network of Marine Protected Areas (MPAs) was created throughout the Bight (CDFG 2012). These MPAs were generally placed on rocky headlands, as this habitat is limited in the region. This limited reef habitat was the most contentious issue during the implementation process even though the amount of this reef habitat and the relative spatial distribution and characterization remained unknown making current and future evaluations difficult (Pondella 2009). Marine Protected Areas in California limit catch of extractable resources within their boundaries (CDFG 2012). The establishment of these MPAs, while not specifically designated as fishery management tools during implementation, was in part due to the decline of commercial and recreational fisheries. Fisheries associated with rocky reefs in the region have been particularly impacted. Examples include rockfishes (Love et al. 1998), abalone (CDFG 2005) and most recently the kelp and sand basses (Erisman et al. 2011), and these serial depletions have caused

significant socioeconomic damage. A critical task for advancing various research, restoration, assessment and resource management programs is the quantification and characterization of this nearshore habitat.

While general biogeographic patterns have been discerned for this ecosystem (Murray and Littler 1981, Pondella et al. 2005), the gap in our knowledge of the quantity, structure and habitat quality of shallow nearshore reefs in the SCB is surprising. These gaps in knowledge are similar in other ecosystems where management actions need to be implemented and managers are challenged by a paucity of quantitative data (Mumby and Harborne 1999, Pittman et al. 2011). Further complicating our understanding of this nearshore ecosystem is the necessity of modeling processes on both small and large spatial scales (10^1–10^5 m) (Garcia-Charton 2004) as physical forcing and associated oceanographic conditions will be critical for contextualizing reef performance into the future. Similarly, easily expressible metrics of ecosystem health are needed for managers and non-scientific audiences. While the declines in fishery species are well documented, the effects of pollution on rocky reefs in this area are not well understood. Whether analyzing pollution, fishing practices, or ecological performance (including MPA effectiveness), these processes are all couched within the extent, characteristics and variation in the underlying habitat. Here we report on a novel method to determine the spatial scale of reefs in the SCB. Then, we contextualize this system by describing the underlying substructure and amount of nearshore rocky reefs in the region establishing a template for future research.

Materials and Methods

The methods in this study were composed of three sections. First, we assembled and mapped all the available GIS layers for the region. The remote sensing techniques used in this study did not characterize reef types. Thus, these hard bottom layers were then reviewed by experts in the region to determine accuracy and characterize habitat types. Following this mapping exercise, we conducted a stratified random draw to determine sites for a field-sampling program based upon biogeographic region (which were based upon fish assemblages) insuring statistically equal representation of reefs throughout the SCB. The field-sampling program then characterized a subset of reefs allowing inferences to the reef types of the SCB as a whole.

Mapping.—The best available compilations of mapped rocky reef habitat in the SCB were assembled using GIS. These included maps of hard bottom habitats and kelp canopy (Kelner 2005). GIS spatial analysis techniques were used to integrate existing spatial data that characterizes bottom type, kelp cover, and bathymetry to create a preliminary habitat map. Using these data in GIS, we met with experts who have conducted multiple subtidal scuba research projects on various geographic areas of the SCB. These working groups delineated reefs (< 30 m depth) (Figure 1) and categorized each as either a major reef complex, patchy reef complex, cobble reef, offshore or pinnacle reef, or manmade. Reef dimensions were made based upon the available GIS layers, while reef types were based upon expert opinion. The size of each reef was calculated in GIS and categorized as large, medium or small based upon the distribution of reef sizes. All other nearshore (< 30 m depth) substrate was classified as soft bottom. In better-studied regions (e.g., Palos Verdes, Santa Catalina Island) investigators identified reefs on a finer scale (continuous reef tracts were identified as multiple smaller reefs). Therefore, so as not to bias the sampling draw by these regions for the survey portion of this study (see below), reefs in these regions were grouped into larger reef areas. Similarly, to not deemphasize large reef tracks, reef designations were adjusted to be as consistent as possible in size and distribution throughout the bight while mindful of natural habitat gaps. At Horseshoe Kelp in Los Angeles County and Point Loma, the large reef areas were broken into two and three reefs, respectively, for the sampling draw so as to not underestimate their impact.

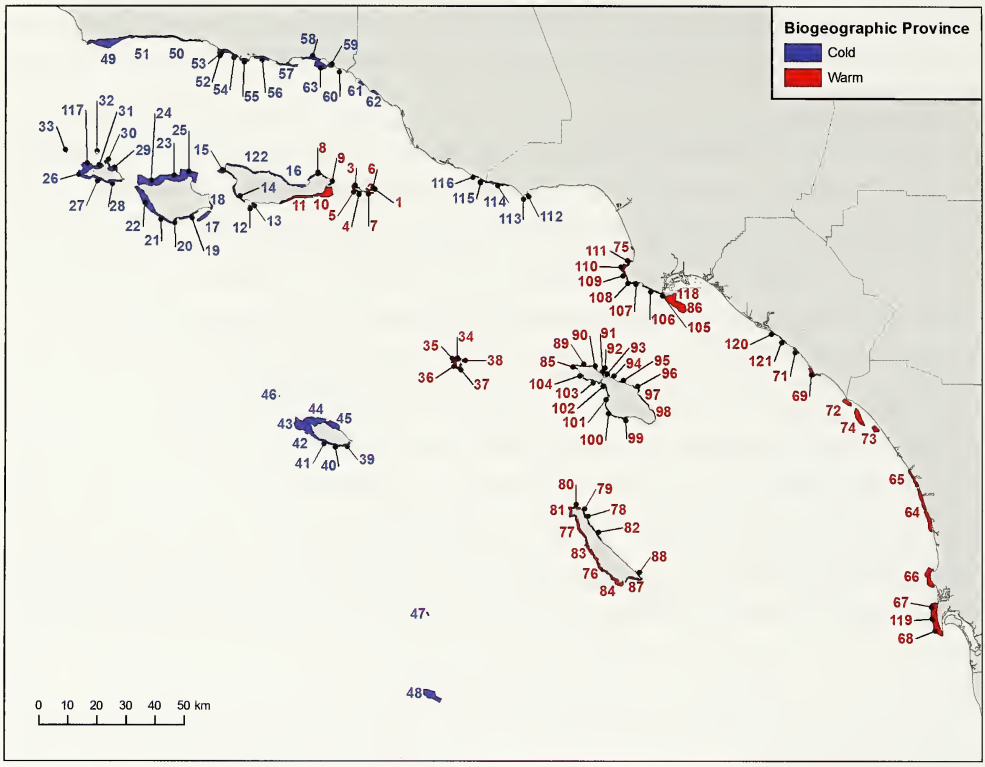

Fig. 1. Nearshore rocky reefs of the SCB. Reefs are color coded by biogeographic province (cold vs. warm) and numbers correspond to the table used for the sampling draw (Appendix 1).

Station Draw.—Reefs were coded as island or mainland within each biogeographic province, San Diegan (warm temperate) or Oregonian (cold temperate). Biogeographic province (Appendix 1) was determined for the eight Channel Islands by biogeographic assessment of benthic fish assemblages studied during the 2003–04 CRANE survey (Tenera 2006). In this biogeographic analysis young-of-year (YOY) fishes whose density is seasonal, and highly abundant pelagic species (*Engraulis mordax* and *Sardinops sagax*) present at only two sites, were excluded from the data set. All statistics were run using PRIMER (version 6). The number of fishes observed by station was Log (x+1) transformed. A Bray-Curtis similarity matrix was then calculated and a hierarchical cluster analysis was performed. Using the similarity matrix, nonmetric multi-dimensional scaling was performed and using 45% similarity ellipses calculated from the Bray-Curtis cluster the biogeographic regions were determined (Figure 1, Appendix 1). Mainland reefs were divided along previous described biogeographic assemblages utilizing Santa Monica Bay as the faunal break between Oregonian and San Diegan faunas (Horn and Allen 1978, Horn et al. 2006). Manmade reefs (i.e., breakwaters and jetties) were not included in this mapping effort because they are well mapped and not part of the random station draw. For the spatial scale aspect of this program, 60 natural rocky reefs (Figure 1; Appendix 1) from this map were selected using a nested random draw (Stevens and Olsen 2004), a probability-based design developed for monitoring aquatic resources, through EPA's Environmental Monitoring and Assessment Program (EMAP) (Stevens 1999). The advantage of the generalized random tessellation stratified design (GRTS) is that it allows for random sampling in a way that provides good spatial coverage (without the clumping of sites often seen with simple

random sampling). In addition, various strata or subpopulations can be defined and weighted proportionally to a host of subpopulation characteristics (e.g., the size of the resource, the size of the reef, variability of subpopulation estimates) so as to maximize efficiency when estimating population totals or comparing among subpopulations. Two additional reefs (Escondido and Big Rock) were not included in the random draw but were sampled as a part of this study to fill in a gap in Santa Monica Bay.

Field Sampling.—teams of SCUBA divers that accessed sample sites from a research vessel collected data visually. A single site consisted of at least 250 m of reef habitat. Within each site four depth strata (if present) were sampled and geo-referenced. These strata were the inner (~5 m), middle (~10 m), outer (~15 m) and deep (~25 m) portions of a natural reef. Within each depth stratum Uniform Point Contact (UPC) sampling protocol was completed. Therefore, the maximum sampling effort for a site includes 8 UPC transects – 2 transects per each of the 4 depth strata. All transects were 30 m in length. Substrate type and relief were recorded at each meter mark along the 30 m transect tape to estimate percent cover. Substrate type was defined as: bedrock (>1 m), boulder (1 m–10 cm), cobble (<10 cm), or sand. Substrate relief was defined as the maximum relief (0–0.1 m, 0.1–1 m, 1–2 m or >2 m) within a rectangle centered on the point that is 0.5 m along the tape and 1 m wide. The percentage of each type of substrate category (bedrock, boulder, cobble or sand) was determined by pooling the number of contact points for all replicates at each site by category, and dividing the sum of each category by the total number of contact points at that site. Percentage of reef relief category (0–0.1 m, 0.1–1 m, 1–2m or >2m) was calculated in the same manner. Reef structure categories (% relief and substrate) were square root transformed and normalized prior to being clustered using Euclidean distances.

Results

In our calculations the southern California coastline is 1198 km in length. The islands comprise 503 km of coastline while the mainland coast has a length of 695 km. On the mainland, rocky reefs are offshore (within 500 m) of 176 km (25.4%) of the coastline. At the islands, reefs are offshore of 377 km (75.1%) of the coastline. For the islands the faunal break was in the middle of Santa Cruz Island, on the mainland it fell in the middle of Santa Monica Bay (Figure 1). In the cold temperate region reefs span offshore of 290 km of the coast and in the warm temperate region they span 263 km of coastline. We identified 122 natural reefs (< 30 m depth) comprising 49,055 hectares in the SCB (Figure 1, Table 1). A greater fraction (60.8%) of reefs were found in the cold temperate. This was in part due to the Santa Rosa and San Nicolas Islands where the greatest expanse of reefs were identified (9088 and 5250, respectively). A priori, eighty-nine reefs were classified as major reef complexes, seventeen as patchy reef areas, two cobble reefs, and twelve pinnacle/offshore deep reefs (Appendix I). 10,164 ha of the reefs identified in this study were previously described as soft bottom habitat. Demarcated by the 30-m isobath, there are 184,439 ha of nearshore habitat in the bight, of which reefs comprised approximately a quarter (26.6%) while the remainder was sand.

Natural reefs (< 30 m depth) ranged in size from 6.2 (Begg Rock) to 2498 ha (Cojo) followed by Talcott at Santa Rosa Island (2493 ha) (Appendix 1). The total for three Point Loma reef designations, which are continuous, is 2296 ha. Santa Rosa and San Nicolas Islands contained the largest contiguous reef tracks and kelp beds in the SCB. The lee of Santa Rosa Island (Rodes, Talcott and Carrington Point) comprised 5284 ha and the four reefs at west end of San Nicolas Island comprised 4663 ha. On the mainland, Cojo Anchorage was the largest reef (2498 ha) followed by three Point Loma reefs. The mean size of a natural reef was 409 hectares (sd $\pm$ 497). The distribution of reef areas was plotted and reefs were classified into three size classes. Sixty-

Table 1. The following metrics for the Southern California Bight are summarized below for the islands, mainland, the cold temperate (Oregonian) and warm temperate (San Diegan) provinces: the length of the Southern California coastline (Mexico to Point Conception); reef coastline length in km (reefs which are within 500 m of the coast); and the area of natural reef habitat. The total amount of nearshore habitat in SCB is 184,439 and the non-reef habitat is primarily sand.

SCB coastline length (km)			
Mainland	694.5		
Island	502.7		
Total	1197.2		
Reef coastline length (km)			
Mainland	176.2	Cold	290.7
Island	377.4	Warm	262.9
Total:	553.6	Total:	553.6
Reef habitat (ha)	**Cold**	**Warm**	**Total**
Mainland	8213.8	10823.6	19037.4
Island	21587.4	8430.1	30017.4
Anacapa		545.1	545.1
Cortez Bank	1359.6		1359.6
San Clemente		3593.2	3593.2
San Miguel	3461.8		3461.8
San Nicolas	5249.9		5249.9
Santa Barbara Island		888.5	888.5
Santa Catalina		931.1	931.1
Santa Cruz	2365.4	2472.3	4837.7
Santa Rosa	9087.5		9087.5
Tanner Bank	63.2		63.2
Grand totals:	29801.2	19253.7	49054.9

seven reefs were classified in the small category (6–293 ha), with 40 as medium (325–932 ha) and 13 as large (1086–2498 ha). Reef size categories had a mean of 95 ha (sd $\pm$ 69) for small reefs, 558 ha (sd $\pm$ 183) for medium reefs and 1567 (sd $\pm$ 484) ha for large reefs.

To begin to assess the range in physical habitat characteristics of the nearshore rocky reefs in the SCB, we began with a physical characterization of the reef habitat including substrate type and relief (Appendix II). Island reefs were primarily composed of bedrock or boulders (85.9%) while mainland reefs had a more even mix of substrate types (Figure 2). Nearly half (47.8%) of mainland reefs had a 0–0.1 m relief – more than double the fraction at the islands (23.3%). The amount of 1–2 m and >2 m relief reef habitat at the islands were 2 and 6 times the fraction found on the mainland, respectively. For relief, breakwaters were generally more similar to island reefs. Reef structure, classified by relief and substrate through cluster analysis and overlaid on a nMDS plot (Figure 3; Appendix II), varied from an oceanic pinnacle (Begg Rock) that was a sheer vertical structure composed of bedrock and an intertidal component to mainland reefs such as Carp Reef with large fractions of sand with little relief. Five reefs were not classified into a reef type (Figure 3) since they did not form distinct clusters in the cluster analysis (i. e., had relatively high distance from the other reefs). Five reef types were found. Type 1 included a pinnacle reef (Begg Rock) and breakwaters comprised almost completely of bedrock or large boulders. The second grouping (Type 2) was low relief and cobble reefs (Carp Reef and La Jolla) that had significant fractions of sand. Type 3 reefs were predominantly island reefs with some exceptions (Big Rock, Cabrillo Breakwater, Point Loma North, Point Vicente and Little Corona). These reefs were almost completely composed of high relief (1–2 m) bedrock.

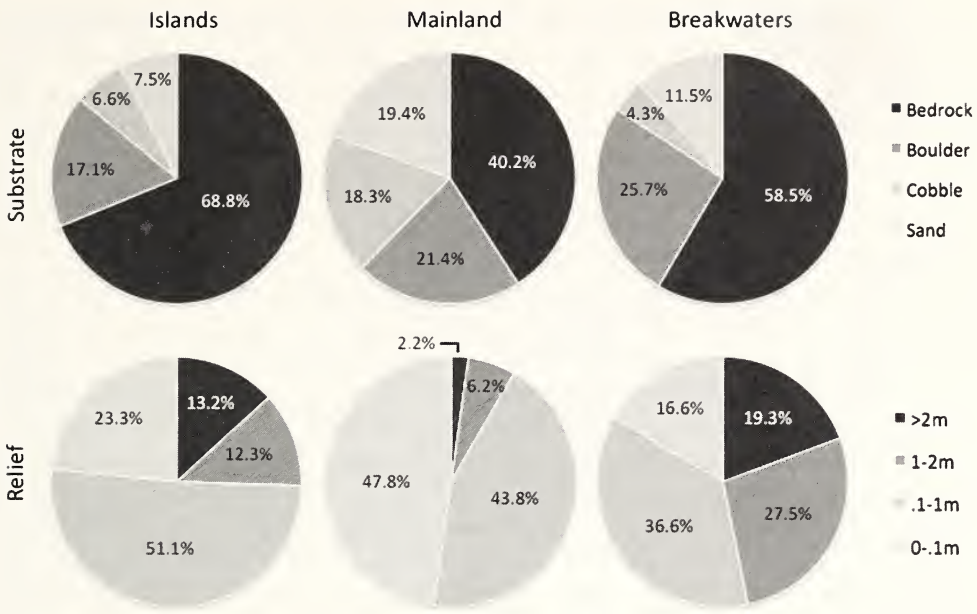

Fig. 2. Substrate type and relief categories for island reefs, mainland reefs and breakwaters.

Alternatively, Type 4 reefs were predominantly mainland reefs with three island reefs (East Quarry, SCAI, Lil Flower, SCLI, and Lion's Head, SCAI). These reefs were comprised of bedrock and boulders with large fractions of lower relief (0–1 m) components. Type 5 reefs were bedrock reefs that were primarily flat (0–0.1 m relief). Thus, reefs can be grouped into five major reef categories: low relief and cobble (Type 2), flat reefs (Type 5), moderate relief (Type 4), high relief (Type 3), and pinnacles (Type 1). Three of these reefs (Banana Rock, Southeast Rock and Point Dume), found on the perimeter of the nMDS plot, were pinnacle reefs (similar to Type 1) that jut abruptly up from a sandy substrate. These types of habitats can be particularly difficult to sample with a 30 m tape, as portions of the transect may wind up on the sand, obfuscating the results.

Discussion and Conclusions

While the 122 natural reefs that were identified in the SCB spanned three orders of magnitude in size (6 to 2498 hectares), most were relatively large major reef complexes and they were distributed throughout the San Diegan (warm temperate) and Oregonian (cold temperate) biogeographic regions. Island reefs tended to be higher relief, primarily bedrock. In general Mainland reefs were lower relief and had more variable substrate composition. Mainland reefs typically were associated with littoral cells and longshore sediment transport and have larger fractions of sand (Figure 2)(Inman and Frautschy 1966). We report that approximately a quarter of the nearshore (<30 m) habitat of the bight is comprised of rocky reef habitat. This is a greater percentage than would be expected from just analyzing the GIS layers available in 2008 (Kelner 2005) or from an extrapolation based upon rocky intertidal habitat (Stephens et al. 2006). This technique was successful at elucidating some generally unexpected patterns. The largest reefs in the SCB and the western coast of North America were at Santa Rosa and San Nicolas Islands. The kelp forest on west end of San Nicolas Island, while not the longest in terms of linear coastline, illustrated the utility of this study. The potential contribution of large reef islands

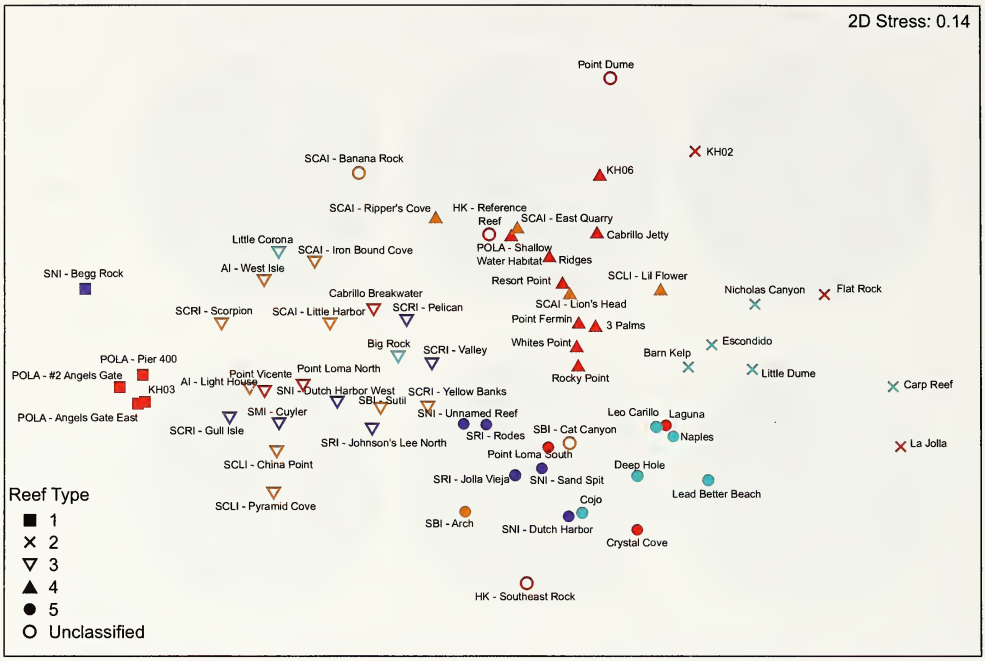

Fig. 3. Reef structure nMDS plot based on Euclidean distances using UPC substrate and relief measures. Reef Type determined by cluster analysis. Colors refer to biogeographic provinces: blue = cold temperate islands, orange = warm temperate islands, light blue = cold temperate mainland, red = warm temperate mainland.

habitats to the ecology of this region is important. This study also identified a substantial amount of the previously described soft bottom habitat as hard bottom by experts and over flight data of giant kelp canopy. Part of this difficulty is that side scan surveys are limited to the perimeter of kelp beds and the nearshore environment changes over time, but utilizing multiple data layers increases the detection of reefs. More fine-grained reef mapping approaches have been and continue to be developed since this program (e.g., Claisse et al. 2012, Parnell 2015). Incorporating more data layers in the future will increase the accuracy of this reef layer.

What is evident is that the nearshore rocky reefs in the SCB are highly variable in terms areal extent and physical habitat structure. Based upon relief and substrate characteristics alone, there are five major reef types in the SCB. Efforts need to be made to understand the influence of reef habitat characteristics (substrate type, rugosity and relief) on the associated biota (e.g., Parnell 2015). Nearshore reefs in the SCB are typically comprised of igneous, metamorphic or mudstone rock (Emery 1960). These rock types may be the cause of additional habitat variation in terms of the biota they support and the rates at which they erode. Further, the geological processes that created the reefs in the Miocene are manifested in the composition and amount of habitat. The geology of our islands and mainland, while quite variable, mirrors the composition of the proximate reefs. Where volcanic processes (Santa Barbara Island, Begg Rock) and the uplift of the Catalina Schist result in dramatic palisades, the resulting fringing nearshore reefs are also sheer and tight to the shoreline. The Northern Channel Islands are essentially a relocated mountain range and have proportionally large nearshore reefs. The eroding marine benches observed on San Nicolas and San Clemente Islands produced kelp beds. As an example, the entire offshore side of San Clemente Island is a continuous reef and the island is ~34 km in length. The geological processes observed on these islands (eroding anticlines, marine benches, sheer palisades, etc.) are mirrored in the nearshore subtidal habitat.

While macroscale processes vary considerably, individual reefs are significantly diverse as well. This habitat heterogeneity impacts the ecology of the region. In the SCB, rocky reef vertical relief was correlated with increased fish density and production with high relief reef significantly outperforming low relief reefs (Ambrose and Swarbrick 1989, Anderson 1989, Pondella et al. 2002, Pondella et al. 2006). Depth has also been shown to be a useful characteristic in modeling reef habitats (Claudet et al. 2006, Claisse et al. 2012, Parnell 2015); we did not include depth in our analyses here, but note that depth components may be a significant factor in reef performance. For instance, Horseshoe Kelp (in Los Angeles County) was only distributed in the deepest strata while many others lacked a deep stratum and some did not have a shallow stratum. A finer-scaled approach evaluating the influence of depth strata on reef performance would be beneficial. The structure, amount and distribution of reefs in the SCB vary appreciably and are important to consider in the potential performance of this system.

Approximately 122 natural rocky reefs/reef complexes comprise approximately one-quarter (26%) of the subtidal habitat in the nearshore (<30 m depth) SCB. Prior to this study, estimates of nearshore subtidal (<30 m) rocky reef habitat were inferred from the linear distribution of intertidal rock and these estimates significantly underestimated the amount of shallow subtidal reef habitat in the SCB. The mapping exercise undertaken in this region was the most exhaustive to date and is the best estimate of reef area for the region. We were able to accomplish this effort relatively quickly and inexpensively using previously collected data sets and expert interviews. Data from multiple sources including side-scan sonar, aerial overflights, satellite imagery, subtidal visual surveys and professional judgments were combined to create our estimates of habitat extent. As more spatial data sets become available, they should be integrated into more fine-scaled reef maps.

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Literature Cited

Ambrose R.F., and S.L. Swarbrick. 1989. Comparison of fish assemblages on artificial and natural reefs off the coast of southern California. Bulletin of Marine Science, 44:718–733.

Anderson T.W., E.E. DeMartini and D.A. Roberts. 1989. The relationship between habitat structure, body size and distribution of fishes at a temperate artificial reef. Bulletin of Marine Science, 44:681–697.

Atwater T.M. 1989. Plate tectonic history of the northeast Pacific and western North America. Pp. 21–79 in The Geology of North America, Vol. N, The Eastern Pacific Ocean and Hawaii (Winterer, E.L., D.M. Hussong and R.W. Decker, eds.). The Geological Society of America.

Atwater T.M. 1998. Plate tectonic history of southern California with emphasis on the western transverse ranges and northern channel islands. Pp. 1–8 in Contributions to the geology of the northern Channel Islands, southern California (Weigand P.W. ed.). American Association of Petroleum Geologists, Pacific Section.

Bohannon R.G., and E. Geist. 1998. Upper crustal structure and neogene tectonic development of the California continental borderland. Geological Society of America Bulletin, 110:779–800.

CDFG. 2005. Abalone recovery and management plan, final. California Department of Fish and Game. The Resources Agency, Sacramento.

CDFG. 2012. Guide to the southern California marine protected areas: Point Conception to California-Mexico border.

Claisse J.T., D.J. Pondella, II, J.P. Williams, and J. Sadd. 2012. Using GIS mapping of the extent of nearshore rocky reefs to estimate the abundance and reproductive output of important fishery species. PLoS ONE, 7:e30290.

Claudet J., D. Pelletier, J. Jouvenel, F. Bachet, and R. Galzin. 2006. Assessing the effects of marine protected area (MPA) on a reef fish assemblage in a northwestern Mediterranean marine reserve: Identifiying community-based indicators. Biological Conservation, 130:349–369.

Crouch J.K., and J. Suppe. 1993. Late cenozoic tectonic evolution of the Los Angeles basin and inner California borderland: A model for core complex-like crustal extension. Geological Society of America Bulletin, 105:1415–1434.

Dojiri M., M. Yamaguchi, S.B. Weisberg, and H.J. Lee. 2003. Changing anthropogenic influence on the Santa Monica Bay watershed. Marine Environmental Research, 56:1–14.

Ebeling A.W., R. J. Larson, and W. S. Alevizon. 1980. Habitat groups and island-mainland distribution of kelp-bed fishes off Santa Barbara, California. Pp. 403–431in The California Islands, Proceedings of a Multidisciplinary Symposium (D.M. Powers, ed.). Santa Barabara Museum of Natural History.

Emery K.O. 1960. The sea off southern California. John Wiley & Sons, Inc., New York. 365 pp.

Erisman B.E., L.G. Allen, J.T. Claisse, D.J. Pondella, E.F. Miller, J.H. Murray, and C. Walters. 2011. The illusion of plenty: Hyperstability masks collapses in two recreational fisheries that target fish spawning aggregations. Canadian Journal of Fisheries and Aquatic Sciences, 68:1705–1716.

Ford T., and B. Meux. 2010. Giant kelp community restoration in Santa Monica Bay. Urban Coast, 2:43–46.

Foster M.S., and D.R. Schiel. 2010. Loss of predators and the collapse of southern California kelp forests (?): Alternatives, explanations and generalizations. Journal of Experimental Marine Biology and Ecology, 393:59–70.

Garcia-Charton J.A., A. Perez-Ruzafa, P. Sanchez-Jerez, J.T. Bayle-Sempere, O. Renones, and D. Moreno. 2004. Multi-scale spatial heterogeneity, habitat structure, and the effect of marine reserves on western mediterranean rocky reef fish assemblages. Marine Biology, 144:161–182.

Graham M.H., P.K. Dayton, and J.M. Erlandson. 2003. Ice ages and ecological tansitions on temperate coasts. Trends in Ecology and Evolution, 18:33–40.

Hickey B.M. 1993. Physical oceanography. Pp. 19–70 in Ecology of the Southern California Bight (Reisch, D.J, J. W. Anderson, and M.D. Dailey, eds.). University of California Press, Berkeley

Horn M.H., and L.G. Allen. 1978. A distributional analysis of California coastal marine fishes. Journal of Biogeography, 5:23–42.

Horn M.H., L.G. Allen, and R.N. Lea. 2006. Biogeography. Pp. 3–25 in The Ecology of Marine Fishes: California and Adjacent Waters (Allen, L.G., D.J. Pondella II, and M. Horn, eds.). University of California Press, Los Angeles.

Horner R.A., D.L. Garrison, and F.G. Plumley. 1997. Harmful algal blooms and red tide problems on the U.S. West coast. Limnology and Oceanography, 42:1076–1088.

Hubbs C.L. 1960. The marine vertebrates of the outer coast. Systematic Zoology, 9:134–147.

Inman D.L., and J.D. Frautschy. 1966. Littoral processes and the development of shorelines. Proceedings of the Coastal Engineering Specialty Conference, ASCE, Santa Barabar California. Pp. 511–536.

Kelner J.J., R. Christensen, R. Clark, C. Caldow and M. Coyne. 2005. Chapter 2, in: A Biogeographic Assessment of the Channel Islands National Marine Sanctuary (Clark, R., J. Christensen, C. Caldow, J. Allen, M. Murray and S. Macwilliams eds.). NOAA Technical Memorandum NOS NCCOS 21: 89–134.

Kemnitzer L.E. 1933. Geology of San Nicolas and Santa Barbara Islands southern California. Masters Thesis, California Institute of Technology, Pasadena California.

Lekic V., S.W. French, and K.M. Fischer. 2011. Lithosperic thinning beneath rifted regions of southern California. Science, 334:783–787.

Love M. 2006. Subsistence, commercial, and recreational fisheries. Pp. 567–594 in The Ecology of Marine Fishes: California and Adjacent Waters (Allen, L.G., D.J. Pondella II, and M. Horn, eds.). University of California Press, Los Angeles.

Love M.S., J.E. Caselle, and W. Van Buskirk. 1998. A severe decline in the commercial passenger fishing vessel rockfish (*Sebastes* spp.) catch in the southern California bight, 1980–1996. CalCOFI Rep, 39:180–195.

Luyendyk B.P. 1991. A model for neogene crustal rotations, transtension, and transpression in southern California. Geological Society of America Bulletin, 103:1528–1536.

Mumby P.J., and A.R. Harborne. 1999. Development of a systematic classification scheme of marine habitats to facilitate regional management and mapping of Caribbean coral reefs. Biological Conservation, 88:155–163.

Murray S.N., and M.M. Littler. 1981. Biogeographical analysis of intertidal macrophyte floras of southern California. Journal of Biogeography, 8:339–351.

North W.J. 1964. Ecology of the rocky nearshore environment in southern California and possible influences of discharged wastes. International Conference on Water Pollution Research, London, September, 1962, Pergamon Press, Oxford.

Olmsted F.H. 1958. Geologic reconnaissance of San Clemente Island California. United States Department of the Interior. Geological Survey Bulletin 1071-B. United States Government Printing Office, Washington.

Parnell P.E. 2015. The effects of seascape pattern on algal patch structure, sea urchin barrens, and ecological processes. Journal of Experimental Marine Biology and Ecology, 465:64–76.

Pittman S.J., R.T. Kneib, and C.A. Simenstad. 2011. Practicing coastal seascape ecology. Marine Ecology Progress Series, 427:187–190.

Pondella D., II. 2009. Science based regulation: California's marine protected areas. Urban Coast, 1:33–36.

Pondella D.J., and L.G. Allen. 2008. The decline and recovery of four predatory fishes from the southern California bight. Marine Biology, 154:307–313.

Pondella D.J., L.G. Allen, M.T. Craig, and B. Gintert. 2006. Evaluation of eelgrass mitigation and fishery enhancement structures in San Diego Bay, California. Bulletin of Marine Science, 78:115–131.

Pondella D.J., B.E. Gintert, J.R. Cobb, and L.G. Allen. 2005. Biogeography of the nearshore rocky-reef fishes at the southern and Baja California islands. Journal of Biogeography, 32:187–201.

Pondella D.J., II, and L.G. Allen. 2000. The nearshore fish assemblage of Santa Catalina Island. Pp. 394–400 in The Proceedings of the Fifth California Islands Symposium. D.R. Browne, K.L. K.L. Mitchell, and H.W. Chaney, eds.) Santa Barbara Museum of Natural History, Santa Barbara, California.

Pondella D.J., J.S. Stephens, and M.T. Craig. 2002. Fish production of a temperate artificial reef based on the density of embiotocids (teleostei: Perciformes). ICES Journal of Marine Science, 59:S88-S93.

Schiff K. 2003. Impacts of stormwater discharges on the nearshore benthic environment of Santa Monica Bay. Marine Environmental Research, 56:225–243.

Sikich S., and K. James. 2010. Averting the scourge of the seas: Local and state efforts to prevent plastic marine pollution. Urban Coast, 1:35–39.

Steneck R.S., M.H. Graham, B.J. Bourque, D. Corbett, J.M. Erlandson, J.A. Estes and M.J. Tegner. 2002. Kelp forest ecosystems: biodiversity, stability, resilience and future. Environmental Conservation, 29:436–459.

Stephens J.S., Jr., R. Larson, and I. D. J. Pondella. 2006. Rocky reefs and kelp beds. Pp. 227–252 in The Ecology of Marine Fishes: California and Adjacent Waters (Allen, L.G., D.J. Pondella II, and M. Horn, eds.). University of California Press, Los Angeles.

Stevens D.L.J., and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association, 99:262–278.

Stevens J., D. L. and A. R. Anthony. 1999. Spatially restricted surveys over time for aquatic resources. Journal of Agricultural, Biological, and Environmental Statistics, 4:415–428.

Stull J.K., K.A. Dryden, and P.A. Gregory. 1987. A historical review of fisheries statistics and environmental and societal influences off the palos verdes peninsula, california. CalCOFI Rep., 28:135–154.

Tenera Environmental. 2006. Compilation and analysis of CIAP nearshore survey data. California Department of Fish and Game: 80 p.

Zoback M.D., M.L. Zoback, V.S. Mount, J. Suppe, J.P. Eaton, J.H. Healy, D. Oppenheimer, P. Reasenberg, L. Jones, C.B. Raleigh, I.G. Wong, O. Scotti, and C. Wentworth. 1987. Evidence of the state of stress of the San Andreas fault system. Science, 238:1105–1111.

Appendix I. Station numbers corresponding to Figure 1, sampled reefs, biogeographic region, reef category.

Reef #	Region	Reef polygon	Bioregion	# Stations	Latitude	Longitude	Area (Ha)	Reef category
1	Anacapa	Landing Cove	Warm Island		34.017	−119.369	45.0	Major Complex
2	Anacapa	The Hump	Warm Island		34.012	−119.390	91.3	Major Complex
3	Anacapa	Port Rock	Warm Island	1	34.019	−119.437	173.4	Patch Reefs
4	Anacapa	Cat Rock	Warm Island		34.003	−119.418	94.3	Major Complex
5	Anacapa	Coral Reef	Warm Island		34.009	−119.435	59.9	Major Complex
6	Anacapa	Lighthouse	Warm Island	1	34.011	−119.370	55.5	Patch Reefs
7	Anacapa	East Fish Camp	Warm Island		34.005	−119.386	25.7	Patch Reefs
8	Santa Cruz I.	Scorpions	Warm Island	1	34.050	−119.581	324.5	Major Complex
9	Santa Cruz I.	San Pedro Point	Warm Island		34.028	−119.525	103.8	Major Complex
10	Santa Cruz I.	Yellow Banks	Warm Island	1	33.998	−119.544	1267.6	Major Complex
11	Santa Cruz I.	Blue Banks	Warm Island	1	33.980	−119.651	776.3	Patch Reefs
12	Santa Cruz I.	Gull Island	Cold Island	1	33.951	−119.824	56.7	Major Complex
13	Santa Cruz I.	Malva Real	Cold Island		33.958	−119.815	74.8	Major Complex
14	Santa Cruz I.	Morris to Kenton	Cold Island		33.987	−119.874	393.9	Major Complex
15	Santa Cruz I.	Forneys	Cold Island		34.054	−119.923	475.9	Major Complex
16	Santa Cruz I.	Painted Cave	Cold Island		34.067	−119.840	691.5	Patch Reefs
17	Santa Rosa I.	Rosa Pinnacles	Cold Island		33.916	−119.995	632.4	Pinnacle/Offshore
18	Santa Rosa I.	East Point	Cold Island		33.948	−119.969	144.9	Major Complex
19	Santa Rosa I.	Ford Point	Cold Island	1	33.915	−120.054	402.7	Patch Reefs
20	Santa Rosa I.	Johnson's Lee	Cold Island	1	33.900	−120.105	134.6	Major Complex
21	Santa Rosa I.	Chickasaw	Cold Island		33.910	−120.157	618.0	Major Complex
22	Santa Rosa I.	Bee Rock	Cold Island		33.962	−120.218	1871.2	Major Complex
23	Santa Rosa I.	Rodes	Cold Island		34.031	−120.111	1131.4	Major Complex
24	Santa Rosa I.	Talcott	Cold Island		34.021	−120.197	2492.6	Major Complex
25	Santa Rosa I.	Carrington Point	Cold Island	1	34.041	−120.059	1659.8	Major Complex
26	San Miguel I.	Judith Rock	Cold Island		34.034	−120.449	781.2	Major Complex
27	San Miguel I.	Miracle Mile	Cold Island		34.023	−120.394	413.7	Major Complex
28	San Miguel I.	Crook Point	Cold Island		34.015	−120.339	427.7	Major Complex
29	San Miguel I.	Cuyler Harbor	Cold Island	1	34.054	−120.341	427.7	Major Complex
30	San Miguel I.	Harris Point	Cold Island		34.071	−120.363	160.3	Major Complex
31	San Miguel I.	Simonton Cove	Cold Island		34.059	−120.396	409.3	Major Complex
32	San Miguel I.	Wilson Rock	Cold Island		34.100	−120.403	10.3	Pinnacle/Offshore

Appendix I. Continued.

Reef #	Region	Reef polygon	Bioregion	# Stations	Latitude	Longitude	Area (Ha)	Reef category
33	San Miguel I.	Richardson's Rock	Cold Island		34.102	−120.518	16.7	Pinnacle/Offshore
34	Santa Barbara I.	Santa Barbara north	Warm Island	1	33.487	−119.036	82.6	Major Complex
35	Santa Barbara I.	Websters	Warm Island		33.487	−119.053	411.8	Major Complex
36	Santa Barbara I.	Sutil	Warm Island	2	33.470	−119.047	171.7	Major Complex
37	Santa Barbara I.	Southeast Sealion	Warm Island		33.466	−119.031	181.3	Major Complex
38	Santa Barbara I.	Santa Barbara offshore	Warm Island		33.487	−119.019	41.1	Pinnacle/Offshore
39	San Nicolas I.	Daytona Beach	Cold Island	1	33.217	−119.446	186.6	Major Complex
40	San Nicolas I.	Dutch Harbor	Cold Island	1	33.216	−119.486	199.6	Major Complex
41	San Nicolas I.	Station 2	Cold Island	1	33.226	−119.525	194.9	Major Complex
42	San Nicolas I.	Unnamed reef	Cold Island	1	33.246	−119.572	501.5	Major Complex
43	San Nicolas I.	Boilers	Cold Island		33.273	−119.608	1781.6	Major Complex
44	San Nicolas I.	Station 3	Cold Island		33.288	−119.565	1503.2	Major Complex
45	San Nicolas I.	Alpha Foul	Cold Island		33.277	−119.495	876.2	Patch Reefs
46	San Nicolas I.	Begg Rock	Cold Island	1	33.362	−119.696	6.2	Pinnacle/Offshore
47	Tanner Bank	Tanner Bank	Cold Island		32.697	−119.130	63.2	Pinnacle/Offshore
48	Cortez Bank	Cortez Bank	Cold Island		32.446	−119.110	1359.6	Pinnacle/Offshore
49	Mainland	Cojo Anchorage	Cold Mainland	1	34.447	−120.379	2497.5	Major Complex
50	Mainland	Refugio	Cold Mainland		34.463	−120.083	482.9	Major Complex
51	Mainland	Gaviota	Cold Mainland		34.467	−120.219	786.0	Patch Reefs
52	Mainland	Naples Reef	Cold Mainland	1	34.422	−119.952	168.4	Major Complex
53	Mainland	Inshore Naples	Cold Mainland		34.431	−119.939	416.6	Cobble Reefs
54	Mainland	Ellwood	Cold Mainland		34.419	−119.900	140.0	Major Complex
55	Mainland	Isly Reef	Cold Mainland		34.405	−119.862	227.3	Major Complex
56	Mainland	More Mesa	Cold Mainland		34.412	−119.796	480.6	Patch Reefs
57	Mainland	Mohawk	Cold Mainland	1	34.393	−119.699	511.3	Major Complex
58	Mainland	Carp Reef	Cold Mainland	1	34.415	−119.609	472.2	Major Complex
59	Mainland	Rincon	Cold Mainland		34.393	−119.539	197.2	Patch Reefs
60	Mainland	La Conchita Banana	Cold Mainland		34.383	−119.505	9.6	Major Complex
61	Mainland	Soledad	Cold Mainland		34.342	−119.423	160.7	Major Complex
62	Mainland	Pitas	Cold Mainland		34.314	−119.371	198.0	Patch Reefs
63	Mainland	Horseshoe Reef	Cold Mainland		34.394	−119.577	809.6	Pinnacle/Offshore
64	Mainland	Cardiff-Encinitas	Warm Mainland		33.037	−117.301	1448.2	Patch Reefs

Appendix I. Continued.

Reef #	Region	Reef polygon	Bioregion	# Stations	Latitude	Longitude	Area (Ha)	Reef category
65	Mainland	Carlsbad	Warm Mainland		33.136	−117.345	506.2	Major Complex
66	Mainland	La Jolla	Warm Mainland	1	32.831	−117.286	1136.5	Major Complex
67	Mainland	Point Loma north	Warm Mainland	1	32.737	−117.268	673.8	Major Complex
68	Mainland	Point Loma south	Warm Mainland	1	32.667	−117.253	745.4	Major Complex
69	Mainland	Dana Point	Warm Mainland		33.466	−117.724	355.9	Major Complex
71	Mainland	Laguna Beach	Warm Mainland	1	33.534	−117.784	105.1	Major Complex
72	Mainland	San Mateo Kelp	Warm Mainland		33.373	−117.593	460.0	Major Complex
73	Mainland	Barn Kelp	Warm Mainland	1	33.292	−117.487	379.2	Major Complex
74	Mainland	San Onofre	Warm Mainland		33.328	−117.548	931.6	Cobble Reefs
76	San Clemente I.	East Clemente	Warm Island		32.851	−118.493	712.5	Major Complex
77	San Clemente I.	West Clemente	Warm Island		32.963	−118.571	785.6	Major Complex
78	San Clemente I.	Wilson Cove	Warm Island		33.005	−118.553	202.4	Major Complex
79	San Clemente I.	Reflector Reef	Warm Island		33.027	−118.565	19.1	Major Complex
80	San Clemente I.	Northwest Harbor	Warm Island		33.037	−118.590	204.4	Major Complex
81	San Clemente I.	Target Rock	Warm Island		33.023	−118.610	347.8	Major Complex
82	San Clemente I.	Navy Reef	Warm Island		32.959	−118.516	158.8	Major Complex
83	San Clemente I.	Eel Point	Warm Island		32.902	−118.537	292.9	Major Complex
84	San Clemente I.	China Point	Warm Island	1	32.806	−118.434	478.8	Major Complex
85	Santa Catalina I.	West Kelp	Warm Island		33.470	−118.601	24.7	Major Complex
86	Mainland	Horseshoe Kelp 1	Warm Mainland	2	33.664	−118.217	1131.0	Pinnacle/Offshore
87	San Clemente I.	Pyramid Cove	Warm Island	1	32.817	−118.376	349.5	Major Complex
88	San Clemente I.	Lil Flower	Warm Island	1	32.830	−118.360	41.5	Major Complex
89	Santa Catalina I.	Parson's Landing & Black Pt	Warm Island		33.476	−118.566	112.8	Major Complex
90	Santa Catalina I.	Indian Rock	Warm Island		33.470	−118.528	31.6	Major Complex
91	Santa Catalina I.	Lionhead	Warm Island	1	33.452	−118.501	26.8	Major Complex
92	Santa Catalina I.	Ship Rock and Eagle Reef	Warm Island		33.461	−118.506	13.1	Pinnacle/Offshore
93	Santa Catalina I.	Blue Cavern and Wrigley	Warm Island		33.447	−118.486	38.3	Major Complex
94	Santa Catalina I.	West Quarry	Warm Island		33.441	−118.464	11.3	Major Complex
95	Santa Catalina I.	Rippers Cove	Warm Island	1	33.428	−118.431	33.9	Major Complex
96	Santa Catalina I.	Hen Rock and Italian Gardens	Warm Island		33.408	−118.375	54.2	Major Complex
97	Santa Catalina I.	Torqua	Warm Island		33.372	−118.347	70.4	Major Complex
98	Santa Catalina I.	East Quarry and Lovers Cove	Warm Island	1	33.333	−118.309	28.4	Major Complex

Appendix I. Continued.

Reef #	Region	Reef polygon	Bioregion	# Stations	Latitude	Longitude	Area (Ha)	Reef category
99	Santa Catalina I.	Salte Verde	Warm Island		33.316	−118.420	132.8	Major Complex
100	Santa Catalina I.	Ben Weston	Warm Island		33.340	−118.476	115.7	Patch Reefs
101	Santa Catalina I.	Little Harbor	Warm Island	1	33.375	−118.483	29.9	Major Complex
102	Santa Catalina I.	Pin Rock to Banana Rock	Warm Island	1	33.410	−118.492	105.3	Major Complex
103	Santa Catalina I.	Cape Cortez and Lobster Bay	Warm Island		33.429	−118.530	45.4	Major Complex
104	Santa Catalina I.	Ironbound and Ribbon Rock	Warm Island	1	33.439	−118.568	56.6	Major Complex
105	Mainland	Point Fermin Reef	Warm Mainland	1	33.705	−118.288	36.9	Major Complex
106	Mainland	Bunker Point to Whites Point	Warm Mainland	2	33.717	−118.327	177.7	Major Complex
107	Mainland	Abalone Cove	Warm Mainland		33.739	−118.382	50.0	Patch Reefs
108	Mainland	Point Vicente to Long Point	Warm Mainland	1	33.739	−118.406	78.9	Major Complex
109	Mainland	Rancho Palos Verdes	Warm Mainland	1	33.760	−118.422	98.6	Major Complex
110	Mainland	Rocky Point and Ridges	Warm Mainland	2	33.783	−118.429	356.2	Major Complex
111	Mainland	Flat Rock	Warm Mainland	1	33.800	−118.407	84.6	Major Complex
112	Mainland	Little Dume	Cold Mainland	1	34.007	−118.791	60.6	Major Complex
113	Mainland	Point Dume	Cold Mainland	1	33.999	−118.806	7.3	Pinnacle/Offshore
114	Mainland	Leo Carrillo to Encinal	Cold Mainland	2	34.039	−118.908	362.8	Major Complex
115	Mainland	Deep Hole	Cold Mainland	1	34.047	−118.965	163.0	Major Complex
116	Mainland	Deer Creek	Cold Mainland		34.060	−118.986	62.1	Major Complex
117	San Miguel I.	Castle Rock	Cold Island		34.058	−120.437	815.0	Major Complex
118	Mainland	Horseshoe Kelp 2	Warm Mainland		33.689	−118.249	1086.4	Pinnacle/Offshore
119	Mainland	Point Loma middle	Warm Mainland		32.702	−117.266	877.2	Major Complex
120	Mainland	Little Corona	Warm Mainland	1	33.586	−117.867	49.7	Patch Reefs
121	Mainland	Crystal Cove	Warm Mainland	1	33.566	−117.834	54.6	Patch Reefs
122	Santa Cruz I.	Pelican	Cold Island	1	34.031	−119.683	672.5	Patch Reefs
-	Mainland	Escondido	Cold Mainland	1	34.020	−118.772	-	-
-	Mainland	Big Rock	Cold Mainland	1	34.035	−118.608	-	-
KH	Breakwaters	King Harbor	Warm Mainland	3	33.842	−118.397	-	Manmade
POLA	Breakwaters	Port of Los Angeles	Warm Mainland	6	33.710	−118.260	-	Manmade

Appendix II. Percent substrate type and relief.

			Substrate				*Relief*			
Reef #	Region	Station	Bedrock	Boulder	Cobble	Sand	0-.1m	.1-1m	1-2m	>2m
29	San Miguel I.	Cuyler	88	1	9	1	1	67	14	18
25	Santa Rosa I.	Rodes	9	1	8	1	34	67		
20	Santa Rosa I.	Johnson's Lee North	81	3	9	8	11	67	15	6
19	Santa Rosa I.	Jolla Vieja	77			23	48	52	<1	
122	Santa Cruz I.	Pelican	6	13	17	9	8	68	24	1
8	Santa Cruz I.	Scorpion	59	27	2	13	10	36	16	38
12	Santa Cruz I.	Gull Isle	88	1	6	5		56	19	24
11	Santa Cruz I.	Valley	66	6	13	15	4	93	2	1
10	Santa Cruz I.	Yellow Banks	72	4	18	6	11	82	4	3
3	Anacapa	West Isle	65	23	6	5	<1	59	31	9
6	Anacapa	Light House	8	9	2	1	4	49	18	29
46	San Nicolas I.	Begg Rock	67	33				2	7	91
42	San Nicolas I.	Unnamed Reef	94	2		3	4	56	4	
41	San Nicolas I.	Dutch Harbor West	94	2		5	7	69	18	6
40	San Nicolas I.	Dutch Harbor	65	4	3	28	69	23	6	2
39	San Nicolas I.	Sand Spit	81	4	1	14	69	29	2	
34	Santa Barbara I.	Arch	91	1	9		62	28	7	3
36	Santa Barbara I.	Sutil	9	1			28	52	15	5
36	Santa Barbara I.	Cat Canyon	52	16	31	1	54	34	1	2
104	Santa Catalina I.	Iron Bound Cove	59	37	1	3	5	56	3	9
102	Santa Catalina I.	Banana Rock	41	51	8	1	18	46	3	33
101	Santa Catalina I.	Little Harbor	69	25	1	6	9	65	9	19
91	Santa Catalina I.	Lion's Head	35	43	13	9	34	59	3	4
95	Santa Catalina I.	Ripper's Cove	4	45	2	13	15	57	26	2
98	Santa Catalina I.	East Quarry	34	63	2		33	58	9	
84	San Clemente I.	China Point	96	4			16	37	20	28
87	San Clemente I.	Pyramid Cove	68	14	9	9	24	23	23	30
88	San Clemente I.	Lil Flower	24	38	17	22	41	43	1	6
49	Mainland	Cojo	76		18	6	76	24		
52	Mainland	Naples	46	24	21	9	79	3		

Appendix II. Continued.

			Substrate				*Relief*			
Reef #	Region	Station	Bedrock	Boulder	Cobble	Sand	0-.1m	.1-1m	1-2m	>2m
57	Mainland	Lead Better Beach	38	1	44	9	81	18	1	
58	Mainland	Carp Reef		16	26	58	9	10		
115	Mainland	Deep Hole	65	18	4	14	9	10		
114	Mainland	Leo Carrillo	36	15	3	46	56	35	9	2
114	Mainland	Nicholas Canyon	7	28	16	48	40	6		
113	Mainland	Point Dume	13	6	27		44	18	39	
112	Mainland	Little Dume	15	19	38	28	56	44		
-	Mainland	Escondido	2	14	27	4	32	68		
-	Mainland	Big Rock	76	2		23		1		
111	Mainland	Flat Rock	1	32	4	28	52	48	1	
110	Mainland	Ridges	31	4	8	21	19	74	6	1
110	Mainland	Rocky Point	53	24	17	6	49	48	3	
109	Mainland	Resort Point	36	43	1	11	27	68	5	<1
108	Mainland	Point Vicente	95	5			4	52	23	22
106	Mainland	3 Palms	41	34	13	12	42	54	4	
106	Mainland	Whites Point	49	28	18	5	45	53	3	
105	Mainland	Point Fermin	39	32	19	1	35	60	4	2
86	Mainland	HK - Reference Reef	34	53	13		19	76	5	
86	Mainland	HK - Southeast Rock	4	19	37	3	44	27	16	13
120	Mainland	Little Corona	49	37	6	9	12	36	33	18
121	Mainland	Crystal Cove	55	2	2	42	82	15	3	
71	Mainland	Laguna	41	15	5	38	69	29	2	
73	Mainland	Barn Kelp	28	2	24	28	49	52		
66	Mainland	La Jolla		7	64	29	93	7		
67	Mainland	Point Loma North	88	2	9	1		76	2	4
68	Mainland	Point Loma South	73	2	4	2	51	49		
KH	Breakwaters	KH02	21	29		5	5	16	34	
KH	Breakwaters	KH03	95	5				13	5	38
KH	Breakwaters	KH06	15	6	3	23	26	59	16	
POLA	Breakwaters	Cabrillo Jetty	23	66	8	3	42	52	6	
POLA	Breakwaters	Cabrillo Breakwater	79	15		6		94	6	

Appendix II. Continued.

			Substrate				*Relief*			
Reef #	Region	Station	Bedrock	Boulder	Cobble	Sand	0-.1m	.1-1m	1-2m	>2m
POLA	Breakwaters	#2 Angel's Gate	81	9		11		16	4	53
POLA	Breakwaters	Angels Gate East	78	11	2	9	2	17	46	35
POLA	Breakwaters	Pier 400	89	1		2		19	32	48
POLA	Breakwaters	Shallow Water Habitat	47	27	26		29	45	26	
	Bightwide		*61*	*16*	*11*	*12*	*31*	*41*	*8*	*7*

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Comparison of the Marine Wood Borer Populations in Los Angeles Harbor in 1950-1951 with the Populations in 2013-2014

Donald J. Reish,[1,*] Thomas V. Gerlinger,[2] and Robert R. Ware[2]

[1]*Department of Biological Sciences, California State University, Long Beach, California 90840*
[2]*Coastal Resources Management, Inc., Long Beach, California 90804*

Abstract.—A 14-month study was conducted of the marine wood borers present on suspended wooden blocks replaced monthly at nine stations in Los Angeles Harbor in 2013-2014, and compared to the results of a marine borer study conducted in 1950-1951. Many environmental changes have occurred in the harbor over the past 63 years. The harbor land mass of the outer harbor has been expanded towards the breakwater, channels deepened, and the water quality improved as a result of pollution abatement. Existing pilings removed, replaced or covered with two layers of polyethylene. The isopod *Limnoria tripunctata* and the bivalve *Lyrodus pedicellatus* were the principal species. The station located in the Consolidated Slip area of the inner harbor was the site of 87 and 58 percent of the *Limnoria* and *Lyrodus*, respectively, counted during the study. Neither of these species present at this station in 1950-1951. The dissolved oxygen concentration at this station improved from a mean of 0.1 ppm in 1950-1951 to a mean of 6.7 in 2013-2014 as a result of improved environmental conditions. Larval settlement at Cerritos Channel numbered in the thousands in 1950-1951 but only 22 were counted during the 2013-2014 survey. This difference was attributed to the effect of piling covering or removal. It is recommended that existing creosoted pilings be covered or removed in the inner harbor area since this was the region of greatest occurrence of wood borers in 2013-2014.

The purpose of this study is to determine if there have been any changes in the marine wood boring animal population in Los Angeles Harbor since the study conducted in 1950-1951. The principal marine wood boring animals in Los Angeles Harbor belong to the isopod genus *Limnoria* and to the bivalve shipworm family Teredinidae. Four species have been reported from Los Angeles harbor: *Limnoria tripunctata, L. quadripunctata, Lyrodus diegensis* [*=Teredo diegensis*] and *Bankia setacea* (Menzies, et al., 1963). Two additional species of crustaceans are known to ingest wood but unknown to cause damage to wood pilings. The amphipod *Chelura terbrans*, which lives within burrows made by L*imnoria,* and the copepod *Tisbe gracilis,* which occurs on wood blocks, ingests wood under laboratory conditions. (Barnard, 1955; Barnard and Reish, 1957).

The earlier study was initiated by Robert J. Menzies who proposed to study the occurrence and biology of the wood boring isopod *Limnoria* in Los Angeles Harbor as the subject for his doctoral dissertation at the University of Southern California. He contacted Carrol Wakeman, chief testing engineer of the Port of Los Angeles, in 1949 for assistance in his proposal. Wakeman was interested and offered the assistance of a boat. Menzies' major professor, Dr. John L. Mohr, suggested that the study be expanded to include the bivalve wood borers and fouling

* Corresponding author: Donald.Reish@csulb.edu

organisms. Mohr then established the Southern California Marine Wood Borer Council. The members included Wakeman, Harold Schiller of Baxter Creosoted Co., and other graduate students of Mohr. The group met in the home of Mohr to plan for the study. The one-year study, of whom the author of this paper (DJR) participated, was initiated in March 1950 and terminated in March 1951. Wood blocks were suspended at three depths for a 28-day period at 15 stations in Los Angeles—Long Beach Harbors. The wood blocks were removed, fouling organisms scrapped off and preserved, replaced with clean wood blocks and the wood borers identified and counted. Additional blocks were suspended for four months in order for the pallets, the identifying systematic character, of the bivalve Family Teredinidae, to mature. Publications on the occurrence of wood borers and fouling organisms as result of this study included: Menzies (1951), Menzies, et al. 1963), Barnard (1950, 1955, 1958), Reish, (1954, 1971a). The Council ceased to exist after the completion of the study. No survey of the occurrence of wood borers in the Los Angeles—Long Beach Harbors has been conducted since 1950-1951. Therefore, the objectives of this study were to compare the occurrence of wood borers in Los Angeles Harbor and their relationship to the environmental conditions in 1950-1951 with those in 2013-2014.

Los Angeles Harbor has undergone many changes in the ensuing 63 years since the previous wood borer study and only those which influence wood borer activity are enumerated herein. The Main Channel and West Basin have been dredged to accommodate larger ships. The harbor land mass has been extended towards the breakwater by construction of Piers 300 and 400 (compare Figure 1a with Figure 1b). Pollution abatement was initiated in the late 1950s and extended into the late 1960s which resulted in an improvement of water quality (Reish, 1971b). Pilings in the harbor were primarily wood timbers which had been creosoted to prevent the infestation of wood borers. However, the isopod *Limnoria tripunctata* is capable of penetrating creosoted wood pilings (Lee and Miller, 1980). The inner harbor area was characterized in the 1950-1951 period with little or no dissolved oxygen (Menzies, et al., 1963). With the improvement of water quality (Reish, 1971b) *L. tripunctata* and to a lesser extent *Lyrodus pedicellatus* was able to infect pilings and other wood structures in the inner harbor. As a means of combating the invasion of wood borers, the harbor department covered the wood pilings with 6 mm inner wrap of polyethylene and 20-30 mm of polyvinylchloride outer wrap which killed any existing borers and fouling organisms by suffocation and excluded new infestations.

Materials and Methods

Station designations coincided, in so far as possible, with those in 1950-1951. The stations are indicated in Figure 1a for the 1950-1951 survey, Figure 1b for those sampled in 2013-2014 and described in Table 1. The study began on August 18, 2013 and terminated on October 1, 2014. Douglas fir wood was purchased from a building supply company as in 1950. The wooden blocks were smooth and without knots. A 1.5 cm diameter hole was drilled in a wood block measuring 3.5 x 15 cm. The block was attached to the rope and suspended at mid-water depth for usually a 28-day period. A rope was weighted at the end and attached to a harbor structure. The block was removed at the end of the time period and replaced with a new block. A second block was attached to the rope at selected stations and removed in approximately four months to examine the pallets to distinguish between the two bivalve teredinid species. The water temperature and dissolved oxygen concentration were measured electronically each time with a YSI 556 multi-parameter meter at a depth of three feet from the surface (Table 1). The fouling organisms were removed from the block with a paint scraper and preserved in formalin for later identification of polychaetes. Each wood block was examined on the day of recovery and the wood borers were identified under a dissecting microscope. *Limnoria*

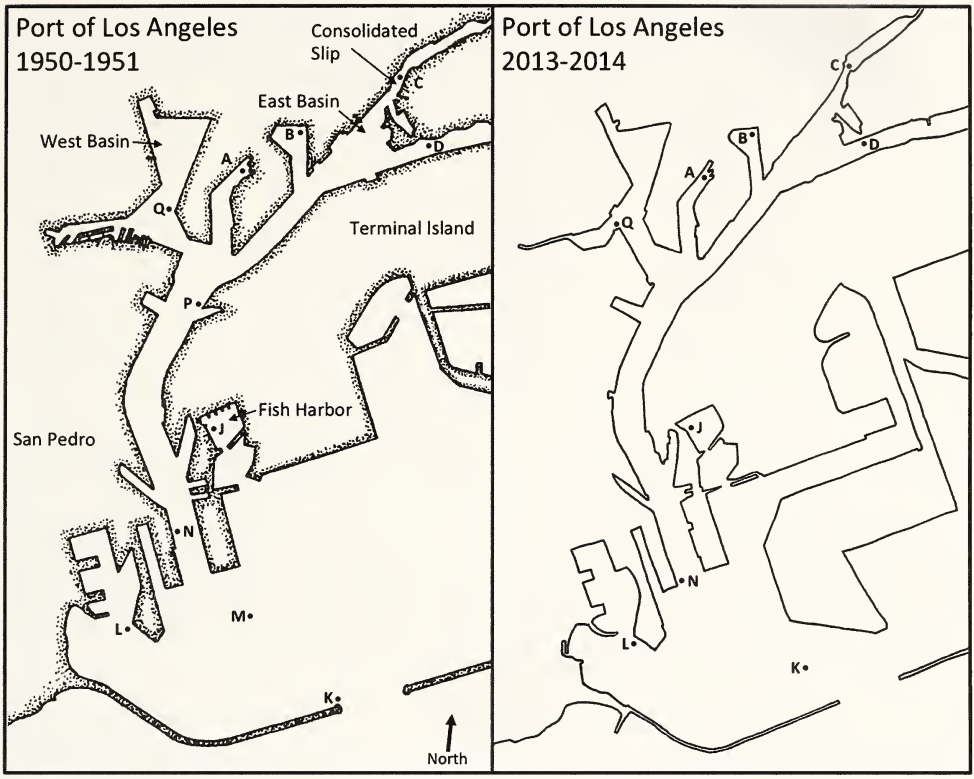

Fig. 1a. Map of Los Angeles—Long Beach Harbors showing the station locations in the Los Angeles Harbor survey conducted in 1950-1951. 1b. Map of Los Angeles Harbor showing the station locations in the 2013-2014 survey.

tripunctata is distinguished from the other species of the genus by the possession of three bumps on the telson which are visible under a dissecting microscope.

Results

Water temperatures three feet below the surface ranged from a low of 13.2°C (55.8°F) at Station K located near the harbor entrance in April 2014 to a high of 22.1°C (71.8°F) at Station C located in the Consolidated Slip area in September 2014 (Table l). The mean temperature in Los Angeles Harbor during the 14-month study period was 17.7°C (63.8°F). The dissolved oxygen concentration ranged from a low of 5.97 ppm at Station D in Cerritos Channel to a high of 10.6 ppm at Station A located in Slip 1 in the inner harbor in December 2013. The mean dissolved oxygen concentration in Los Angeles Harbor for the 14-month study period was 7.6 ppm. Three species of wood borers were present on the test blocks: the isopod *Limnoria tripunctata*, the bivalve *Lyrodus pedicellatus* and the amphipod *Chelura terebrans.* The two colder water species *L. quadripunctata* and *Bankia setacea* present in the 1950-1951 study did not occur in the 2013-1014 study. *Limnoria* was present at all stations but Station K located near the harbor entrance. Station C located in Consolidated Slip accounted for over 87% of the *Limnoria* counted during the 14-month period (Table 2). It was present throughout the survey period at Station C with peaks in occurrence in April through July 2014 on both the monthly and quarterly exposed wood blocks. There were only 19 *Limnoria* present at nearby Station B, the second most in occurrence on the

Table 1. Environmental description, location of stations sampled in 2014-2014.

Station letter	Location	Depth* (in feet)	Water temperature °C range; mean	Dissolved oxygen ppm range; mean
A	Slip 1, Berth 160	11.3	15.3–21.2 (18.1)	6.1–8.5 (7.5)
B	Harbor Basin 5	19.9	14.2–20.4 (17.4)	6.7–8.5 (7.5)
C	Consolidated Slip	39.2	14.9–22.1 (17.7)	6.0–7.8 (6.7)
D	Cerritos Channel	32.4	15.2–20.9 (18.7)	6.6–9.0 (7.6)
J	Fish Harbor	17.9	13.6–22.6 (18.2)	6.7–9.9 (7.6)
K	Shoaling Marker A	20	13.2–21.1 (16.8)	7.3–9.1 (7.5)
L	Entrance W. Channel	31.6	11.3–21.6 (16.9)	6.6–8.6 (7.6)
N	Port Pilot station	20.3	13.4–21.2 (16.9)	7.1–8.8 (7.9)
Q	Entrance W. Basin	47	15.2–21.8 (17.8)	6.5–9.9 (8.1)

* Water depth relative to mean low water in outer Long Beach Harbor.

wood blocks. Only 11 *Limnoria* were counted from the four outer stations J, K, L and N during the 14-month study. *Lyrodus pedicellatus* was present at least once at all stations. Station C in the Consolidated Slip area accounted for 58% with a peak in September through October 2014. Nearby stations Q and B accounted for 19 and 13%, respectively. The bivalve occurred at all four outer station with largest numbers (29) observed at Station L. The amphipod *Chelura terebrans* was only found at Station C with one taken from monthly exposed wood block on October 1 and two from the longterm exposure ending in August in 2014.

Discussion

The mean water temperature at the nine stations in Los Angeles Harbor was similar in both studies with a median of 17.7°C (63.8°F) in 2013-2014 compared to 17.3°C (63.1°F) in 1950-1951. The lowest temperatures were measured in both studies at Station K; the highest temperature, 26.1°C (79°F), occurred at Station Q in the earlier study which was probably the result of shallow water at that time. The highest temperature of 22.6°C (72.7°F) was measured at Station J in Fish Harbor in 2013-2014. The dissolved oxygen concentrations were different with the range and mean of 5.97-10.6 (7.6) ppm in 2013-2014 compared to 0.0-7.7 (2.9) ppm in 1950-1951. The lack of dissolved oxygen occurred several times in the inner harbor and during fish canning season at Station J in Fish Harbor in 1950-1951. Three species of wood borers were present on the test blocks in 2013-2014: *Limnoria tripunctata, Lyrodus pedicellatus,* and

Table 2. Total number of wood borers present on wood blocks 2013–2014.

Station letter	Limnoria		Lyrodus	
	Monthly	Quarterly	Monthly	Quarterly
A	1	*	14	*
B	16	*	65	*
C	244[1]		264[1]	266
D	3	1	15	7
J	2	*	6	*
K	0	*	3	*
L	5	1	25	9
N	5	22	1	8
Q	1	*	63	*

* Quarterly wood blocks not exposed at these stations.

[1] One *Chelura terebrans* taken on October 2104 monthly block and two on the long term block August 2014.

Table 3. Comparison of the monthly total number of wood borers in 1950-1951 with 2013-2014.

	1950–1951[1]		2013–2014	
Station	*Limnoria*	*Lyrodus*	*Limnoria*	*Lyrodus*
A	2	1	1	14
B	rare[2]	rare[2]	16	65
C	0	0	244	26
D	10	28,800	3	15
J	present[2]	present[2]	2	6
K	43	rare[4]	0	3
L	14	18	5	25
N	328	18	5	1
Q	1	1	1	63

[1] Numbers not always given in Menzies, et al., 1963.
[2] *L. tripunctata, L. quadripunctata*, and teredinids present when dissolved oxygen was high.
[3] All *L. quadripunctata*.
[4] *L. pedicellatus* rare in warm periods; 13 *Bankia setacea* in cold periods.

Chelura terebrans. The two colder water species *L. quadripunctata* and *Bankia setocea* were not present in 2013-2014 (Table 3). While the water temperatures were similar, the absence of these two species may be attributed to the lack of floating wood which would bring the colder water species from the north into the harbor by the prevailing California Current. Picking up floating pieces of wood was a convenient source of *Limnoria* which were used in laboratory experiments (Anderson and Reish, 1967). It was not until recent times that floating wood and debris were picked up by harbor personnel. There were three notable differences in comparing the wood borer data: (1) The near absence or lack of *Limnoria* and *Lyrodus* at the inner most harbor Stations A, B, C and Q in 1950-1951 was attributed to little or no dissolved oxygen in the water in 1950-1951, but the majority of these species occurred at these stations in 2013-2014 because of the improvement of water quality (Table 3). (2) Thousands of newly settled larvae of *Lyrodus* were noted at Station D in Cerritos Channel in 1950-1951 (Menzies, et al., 1963) but only a few were present in 2013-2014. This species has a pelagic larval stage and is capable of swimming some distance, but probably the majority came from local untreated or damaged pilings in the earlier study. These pilings had since either been removed or wrapped with polyvinylchloride to prevent infestation. (3) Station N in 1950-1951 was the primary site of *Limnoria* in 1950-1951 but not in 2013-2014 (Table 3) because all wood pilings had been wrapped. Wood borer infestation on test wooden blocks was low in the outer harbor stations and is probably now a minor problem to existing structures.

Conclusions

On the basis of the two studies conducted 63 years apart, the primary area of wood borer activity is now located in the inner harbor area especially at Station C in the Consolidated Slip and to a lesser extent in Basin 5. Three wood boring species were present in 2013-2014: *Limnoria tripunctata*, *Lyrodus pedicellatus* and *Chelura terebans.* The colder water species *Limnoria quadripunctata* and *Bankia setacea* were not taken in 2013-2014. The covering of existing pilings with polyvinylchloride killed any existing populations by suffocation and prevented new infestations. It is recommended that either the existing pilings in Cerritos Channel be covered or removed. As a result, wood boring activity and potential damage will become minimal since new harbor construction predominately uses concrete pilings and any creosoted pilings that are added are wrapped.

Acknowledgements

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Literature Cited

Anderson, J.W. and D.J. Reish, 1967. The effects of varying dissolved oxygen concentrations and temperature on the wood-boring isopod genus *Limnoria.* Marine Biology, 1:56–59.

Barnard, J.L., 1950. The occurrence of *Chelura terebrans* Philippi in Los Angeles and San Francisco Harbors. Bull. So. Calif. Acad. Sci. 49:90–97.

Barnard, J.L., 1955. The wood-boring habits of *Chelura terebrans* in Los Angeles Harbor. *In* Essays in the natural sciences in honor of Captain Alan Hancock. Univ. So. Calif., Los Angeles, p. 87–98.

Barnard, J.L., 1958. Amphipod crustaceans as fouling organisms in the Los Angeles-Long Harbors,with reference to the influence of seawater turbidity. Calif. Fish Game, 43:161–170.

Barnard, J.L., and D.J. Reish., 1957. First discovery of marine wood-boring copepods. Science, 125:236.

Johnson, M.W. and R.J. Menzies, 1956. The migratory habits of the marine gribble *Limnoria tripunctata* Menzies in San Diego Harbor, California. Biol. Bull., 110:54–68.

Lee, W.L. and M.A. Miller, 1980. Isopoda and Tanaidacea: The isopods and allies. Pp. 536–558 in Intertidal Invertebrates of California (Morris, R. H., D. P. Abbott and E. C. Harderlie, eds.). Stanford Univ. Press, Stanford, CA. 690 pp.

Menzies, R.J., 1951. A new species of *Limnoria* (Crustacea: Isopoda) from Southern California. Bull. So. Calif. Acad. Sci., 50:86–88.

Menzies, R.J., J. L. Mohr, and C. M. Wakeman, 1963. The seasonal settlement of wood borers in Los Angeles—Long Beach Harbors. Wasmann J. Biol., 21:97–121.

Menzies, R.J., 1971a. Seasonal settlement of polychaetous annelids on test panels in Los Angeles-Long Beach Harbors 1950-1951. J. Fish. Res. Bd. Canada, 28:1459–1467.

Menzies, R.J., 1971b. Effect of pollution abatement in Los Angeles Harbors. Marine Pollution Bull., 2:71–74.

Reish, D.J. 1954. Polychaetous annelids as associates and predators of the wood borer *Limnoria*. Wasmann J. Biol., 12:223–226.

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Evidence for Negative Effects of Drought on *Baetis sp.* (Small Minnow Mayfly) Abundance in a Southern California Stream

Elizabeth Montgomery,[1]* Rosi Dagit,[1] Crystal Garcia,[1] Jenna Krug,[1] Krista Adamek,[1] Sandra Albers,[1] and Katherine Pease[2]

[1]*Resource Conservation District of the Santa Monica Mountains 30000 Mulholland Hwy, Agoura Hills, CA 91301*
[2]*Heal the Bay, 1444 9th Street, Santa Monica, CA 90401*

Abstract.—Benthic macroinvertebrate (BMI) sampling was conducted at two sites in Topanga Creek from 2003-2014. During this period, Southern California experienced extreme drought conditions (US Drought Monitor 2014). Examining trends in species composition over this period allows for a relatively long-term analysis of potential effects of drought on BMI communities. The Southern California Coastal Index of Biotic Integrity (SCC-IBI; Ode 2007) was applied to BMI samples from Topanga Creek to measure the effects of drought on quantitative biotic integrity. The following trends regarding the BMI community of Topanga Creek emerged during the course of this study: 1) Wet year rainfall in Topanga Creek Watershed positively correlated to relative and per sq. ft. springtime abundance of *Baetis sp.*, relative abundance of *Simulium sp.* up to 78.7 cm (31") rain, and negatively correlated to relative abundance of Chironomidae n. d., 2) percent algae cover in April and May positvely correlated to abundance per sq. ft. *Baetis sp.* and *Simulium sp.*, and 3) multiple regression analysis revealed a negative relationship between Chironomid n.d. and *Baetis sp.* abundance. BMI are an important food source for endangered steelhead trout and other native aquatic and terrestrial insectivorous species of special concern; significant changes to the BMI community could have trophic reprecussions for these and other wildlife. Long-term monitoring is important for tracking the influence of changes in climatic conditions on BMI community.

Introduction

Benthic macroinvertebrate (BMI) communities, made up of snails, worms, insect larvae and nymphs, freshwater crustaceans, and other bottom-dwelling organisms of a freshwater stream, are a vital indicator of riparian ecosystem health (Ode et al. 2005). BMI sampling adds a biotic element to standard water quality testing procedures and is an invaluable tool for ecologists, resource management professionals, and anyone interested in investigating and maintaining healthy rivers (Fetscher et al. 2009). As primary consumers and decomposers of allochthonous and autochthonous detritus, diatoms, and macrophytes, benthic macroinvertebrates are the most basic link between aquatic and riparian vegetation and the rest of the stream community (Merritt et al. 2008, Covich et al. 1999). In Topanga Creek, BMI are an important food item for aquatic reptiles and amphibians, Arroyo chub, and federally endangered southern California steelhead trout. The adult imago of many aquatic insects are an important food source for birds, bats, and other terrestrial insectivores, especially within riparian zones.

Some BMI taxa, such as Ephemeroptera (mayflies), may appear and disappear from the benthos within a matter of weeks, while others, like some Odonata (dragon/damselflies),

* Corresponding author: montgomerylizzy@gmail.com

develop under water over the course of a year or more (Voshell 2002). Shifts in species composition may be the result of a current or past disturbance to stream integrity (Boulton et al. 1992). Habitat preferences, water quality thresholds, and additional life-history traits have been described for nearly 4,000 North American lotic macroinvertebrate species making it possible to key in on the nature of ecological disturbance such as sedimentation, pollution, or increasing temperatures (Vieira et al. 2006). Indices of Biotic Integrity (IBI) have been developed using this information to assign numeric and descriptive scores of ecological health to freshwater systems, such as the Southern California Coastal Index of Biotic Integrity (SCC-IBI) applied here (Fetscher et al. 2009, Ode 2007, Ode et al. 2005).

Drought can negatively affect stream function and aquatic biota by inducing low flows, pool isolation or drying, increased water temperature, sedimentation, and/or reduced dissolved oxygen (Lake 2011). Freshwater habitat and refuges suitable or preferred for particular BMI species can be severely reduced by prolonged drought (Lake 2003). Griswold et al. (2008) found that BMI community composition was altered by drought periods, favoring smaller-bodied species with shorter life cycles. Pool stagnation and fine sediment accumulation associated with drought have been shown to reduce *Baetis sp.* abundance (Iversen et al. 1978, Kaller and Hartman 2004). Less-tolerant or rheophilic families such as Baetidae and Simuliidae can face decline or expiration in prolonged drought conditions, while more tolerant species such as Chironomidae and Ceratopogonidae can become more abundant (Wright and Symes 1999).

The goal of this study was to examine the response of benthic macroinvertebrates to drought in Topanga Creek from 2003 to 2014. Four additional creeks were included to see if any regional patterns emerged within the Santa Monica Mountains (Fig.1). Topanga Creek, Arroyo Sequit, Cold Creek, and Solstice Creek are considered regional reference streams, while a large dam and wastewater treatment plant impact Malibu Creek.

Materials and Methods

Study Location

Topanga Creek, a small perennial coastal mountain stream, drains a 47-km^2 watershed into the Santa Monica Bay, Los Angeles County. The watershed is part of the California Floristic Province biodiversity hotspot and provides vital habitat for federally endangered southern steelhead trout (*Oncorhynchus mykiss)*, 22 species of reptiles and amphibians, and numerous other plants and animals. Approximately 70% of the Topanga Creek watershed is protected parkland managed by California Department of Parks and Recreation. The remaining 30% is developed within the village of Topanga (pop. 8,289, US Census 2010). Both sampling sites are below the village of Topanga, and share a narrow canyon with a two-lane highway that runs alongside the creek in some areas.

Annual BMI sampling in Topanga Creek was carried out from 2003-2014. Drought intensity in this period varied by season and year throughout the decade between periods of normal winter rainfall and extreme drought conditions (US Drought Monitor 2014). The drought intensified as winter rains in 2012 and 2013 were insufficient to alleviate dry conditions, and by 2014 it was declared the worst drought on record since NOAA record-keeping began a century ago (NOAA 2014). Rain data for Topanga, Arroyo Sequit, Malibu, and Solstice watersheds were acquired from the Los Angeles County Department of Public Works. Algae percent cover was recorded during monthly foot surveys throughout the sample reaches 3200-3700m and 4000-4500m.

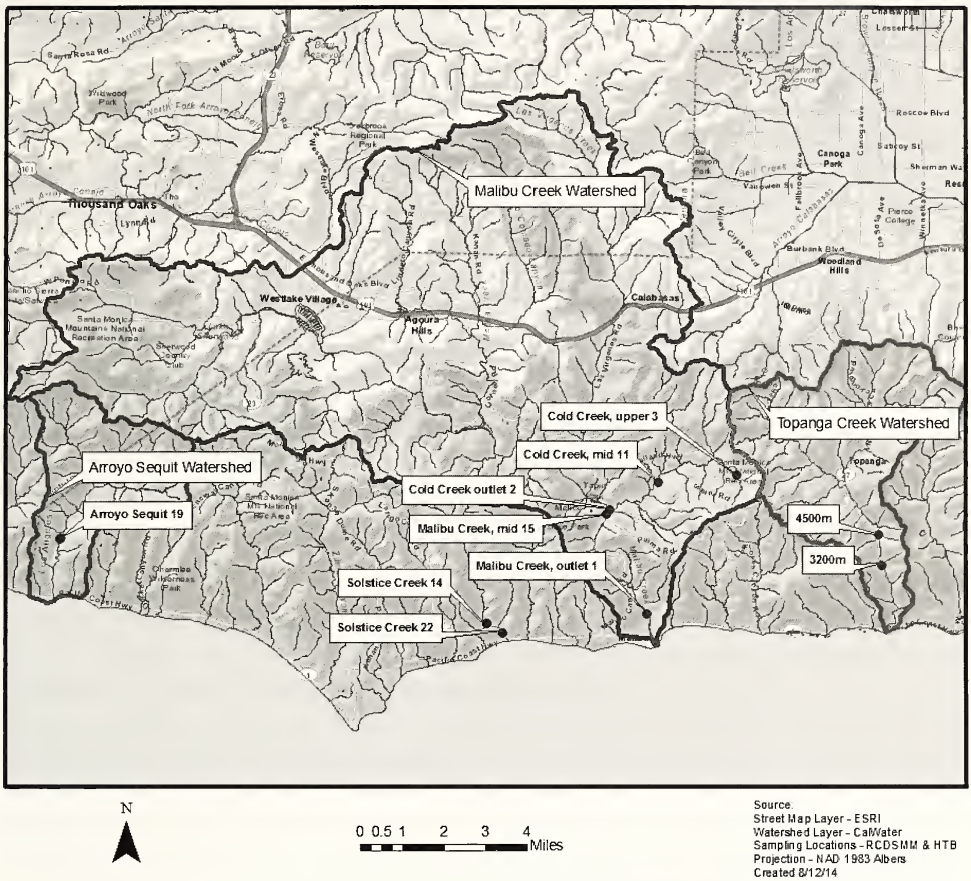

Fig. 1. Topanga Creek and Santa Monica Bay sampling sites 2000-2014. *Lower Topanga at 3200m, Upper Topanga at 4500m.

Sample Collection

BMI samples were collected in spring (Apr 22-May 27) in 2003-2014 (except for 2008 and 2009) at two main stem locations: Upper Topanga (UT; 4500m) and Lower Topanga (LT; 3200m). LT is located within the low gradient (<3%) reach of the creek and UT is located above the Topanga Canyon Bridge (mile marker 2.02) in the higher gradient (3-6%) reach. Sampling protocol in years 2003-2012 followed the California Stream Bioassessment Protocol (CSBP; CDFG 2003). Standard 1-ft. wide D-shape kick nets were deployed left, center, and right of three consecutive riffle transects, for a composite sample of nine kicks. In 2013 and 2014, the SWAMP Bioassessment Procedure (Ode 2007) was employed. A 1-ft D-shape kick net was used to collect samples every 15m along a 150m transect, alternating along the way between 25%, 50% and 75% from right bank, for a composite sample of 11 kicks. Samples collected from UT in 2004 and 2007 were not viable for processing and were not included in the analysis. All Topanga Creek samples were preserved in ⩾90% ethanol or by freezing.

Additional samples were collected from Topanga Creek from five additional sites in May, July, September, November, and December of 2013, and February, April, and June of 2014 following California Stream Bioassessment Method (CDFG 2003) to compare results between sampling methods and examine phenology.

Regional stream survey samples were collected in June or July from 2003-2014 by Heal the Bay (Santa Monica, CA) at four additional upper Santa Monica Bay creeks: Arroyo Sequit (AS19), Cold Creek (CC2, CC3, CC11), Malibu Creek (MC1, MC15), and Solstice Creek (SC14). In 2003 BMI samples were collected using the California Stream Bioassessment Protocol (CDFG 2003); from 2005-2007, sampling was conducted using the US EPA targeted riffle composite (TRC) procedure (Peck et al. 2004; Ode 2007), and starting in 2008, sampling was conducted according to SWAMP Bioassessment Procedure (Ode 2007).

Sample Processing

Using a dissecting microscope, organisms were picked from the sample and then sorted and identified according to standard taxonomic effort or to the lowest practical taxon based on specimen condition and size. Identifications and regional distribution were confirmed using the California DFW Aquatic Bioassessment Laboratory (ABL) Digital Reference Library (CDFW 2014) and Merritt et al. (2008). When identification was not possible, photographs were sent to the CDFW Aquatic Bioassessment Laboratory or identified to the lowest taxonomic level possible and recorded as non-distinct within that taxon. Heal the Bay regional comparison samples were processed by SLSII bioassessment lab.

BMI Analysis

The relative abundance (%) and per sq. ft. abundance of each taxa present was calculated per sample. Processed samples were assessed according to SCC-IBI (Ode et al. 2005). For this index, seven metrics are used to assess ecosystem health: combined taxa richness of Ephemeroptera, Plecoptera, and Trichoptera taxa (EPT), Coleoptera taxa richness, predator taxa richness, % non-insect taxa, % tolerant taxa (TV>7), % intolerant individuals (TV<3), and % collector-gatherer + collector-filterer (CG+CF) individuals. Information regarding tolerance values and functional feeding groups was obtained on CAMLnet (Ode 2003). As SCC-IBI is designed for samples of 500 individuals, samples >500 were subsampled by randomizing sets, generating random numbers and selecting individuals 1-500.

Bray-Curtis Index of Dissimilarity was applied to whole samples, not sub-samples of 500, as it accounts for both sample size and shape (Bray and Curtis 1957).

$$B = \frac{\sum |X_{ij} - X_{ik}|}{\sum (X_{ij} - X_{ik})}$$

Bray-Curtis calculations were based on the abundance per sq. ft. of eight taxa categories: *Baetis sp., Chironomidae n.d., Simulium sp., Ostracod, Elmidae, Acari, Planarian,* and *Hydropsychidae.*

Multiple regression analysis was performed applying a generalized linear model (Poisson regression) run in R software with *Baetis sp.* abundance per sq. ft. as the dependent variable and as a covariate. Other covariate factors input were wet year rainfall, percent algae cover, and Chironomidae n.d. abundance per sq. ft.. *Simulium sp.* was not included because *Simulium sp.* abundance and algae were highly correlated.

Results

BMI Community Composition

A total of 15,303 macroinvertebrates were collected from UT and LT between 2003 and 2014. The number of individuals per sample ranged from 104 to 3,514. Six phyla, 21 orders, and a total of 76 taxa were represented. The majority of individuals (Relative Abundance 'RA' = 89%) fell within the class Insecta. Three genera and one family from class Insecta accounted

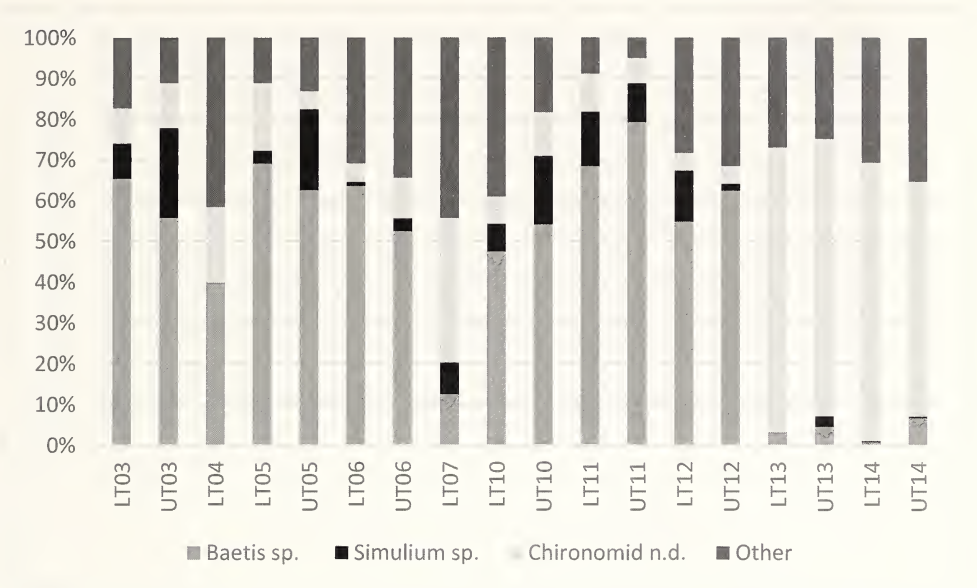

Fig. 2. Relative Abundance of 6 Major Taxon Categories: Upper and Lower Reaches Topanga Creek 2003-2014.

for 76% of total abundance; *Baetis sp.* (small minnow mayflies nymphs, 44% RA), Chironomidae n.d. (non-biting midge fly larva, 23% RA), and *Simulium sp.* (black fly larva, 9% RA; Fig. 2). Other families present throughout the sample period included: Planarian n.d. (flatworms, 3% RA), Elmidae n.d. (riffle beetle larva, 3% RA), Acari (water mites, 2% RA), Hydropsychidae n.d., (net spinning caddisfly larva, 2% RA) and Ostracoda n.d. (seed shrimp, 2% RA).

In samples from 2003-2012, *Baetis sp.* comprised 51% RA ($7.6 \leq n \leq 214.2$ per sq. ft.) and was the first or second most abundant taxa in all samples. In 2013 and 2014, *Baetis sp.* declined to 3% RA (abundance $0.8 \leq n \leq 1.3$ per sq. ft.) of all four samples. *Simulium sp.* abundance decreased from 11% RA 2003-2012, to less than 1% in 2013-2014. Between 2003-2012 and 2013-2014, Chironomidae RA increased from 15% to 66% RA. In samples collected on five occasions from five additional sites in Topanga Creek between May 2013 and June 2014, *Baetis sp.* and *Simulium sp.* each comprised less than 2% of all samples, and never more than 8% of any sample, confirming low abundance across sampling protocols.

Bray-Curtis dissimilarity coefficients for abundance per sq. ft. of eight dominant taxa calculated between all years ranged from 0.06 (LT 2010 to 2011, highly similar) to 0.95 (three pairs, highly dissimilar). Dissimilarity coefficients for 2013 and 2014 were each significantly higher than 2004, 2006, 2007, 2010, 2011, and 2012, $t(14,26) = 2.6 \leq 4.3$, $p < .05$ (two-tailed), upper and lower scores combined. The year 2005 had above average rainfall (61.2 inches) and also a high species composition dissimilarity coefficient. Wet year rainfall explained variation in Bray-Curtis dissimilarity coefficients, which were significantly higher in years with lower rainfall where above average rainfall years 2005 and 2011 were excluded ($R^2=0.85$, $F_{1,13}=30.5$, $p<0.01$).

Functional feeding group composition differed less than taxa composition, and was dominated by collector-gatherers in all years 2003-2014 (range: 63% to 95% RA; Fig. 3). Collector-filterers were the second most abundant feeding group overall, and they declined significantly from 2003-2012 to 2013-2014, $t(16)=2.9$, $p>.05$ (two-tailed).

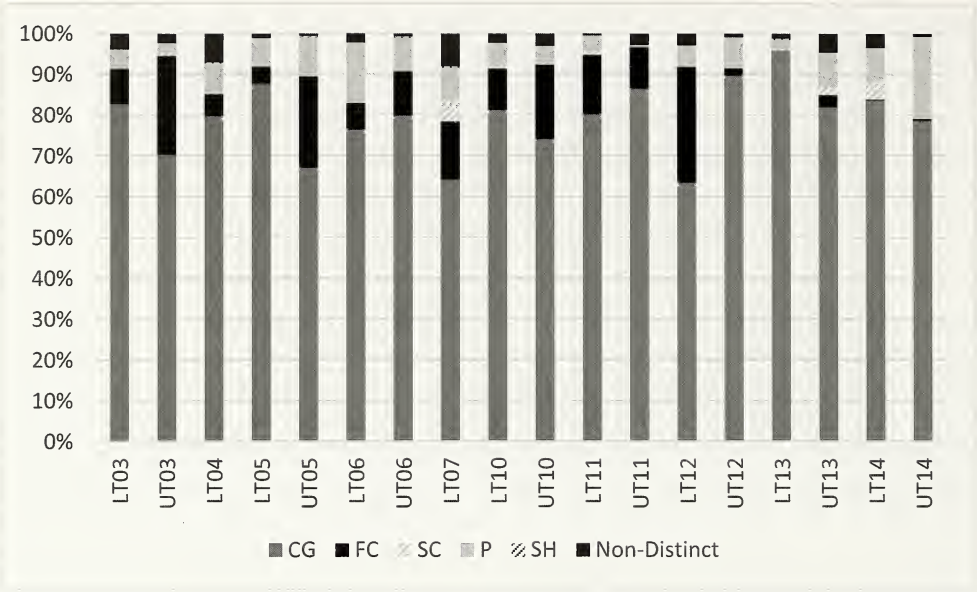

Fig. 3. Relative Abundance of 6 Major Feeding Group Categories: Upper and Lower Reaches Topanga Creek 2003-2014.

Rainfall Correlations

Baetis sp. relative abundance and abundance per sq. ft. significantly and positively correlated to wet year rainfall (WYR; $R^2=0.41$, $F_{1,16}=11.36$, $p<0.01$, $R^2=0.80$, $F_{1,16}=11.36$, $p<0.000001$; Fig. 4a.). Correlation to relative abundance was stronger when above average rainfall in 2005 (61.22") was removed; however *Baetis sp.* abundance measured per sq. ft. was highest this year. *Simulium sp.* RA also positively correlated to wet year rainfall (WYR), only with 2005 data removed ($R^2=0.25$, $F_{1,14}=4.79$, $p<0.05$. Chironomidae n.d. RA negatively correlated to WYR with no upper limit to rainfall ($R^2=0.26$, $F_{1,16}=5.49$, $p<0.05$; Fig. 5). Neither Chironomidae n.d. nor *Simulium sp.* abundance per sq. ft. correlated to WYR, nor did

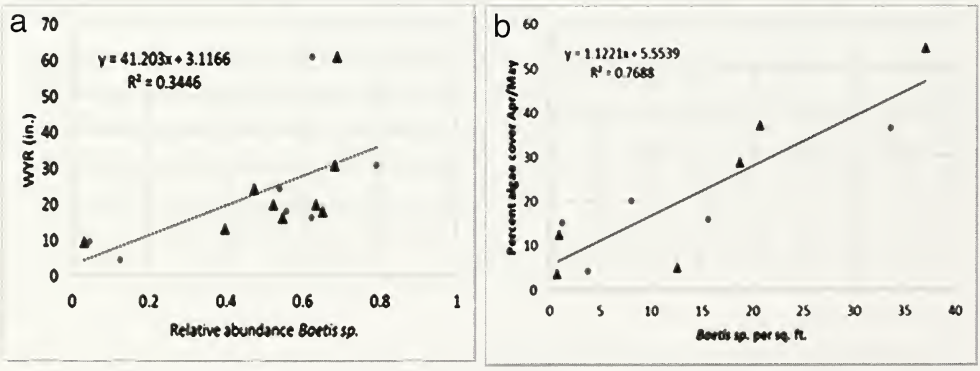

Fig. 4. (a) Relative abundance of *Baetis sp.* and wet year rainfall in Topanga Creek (b) Abundance per sq ft. of *Baetis sp.* and observed algae in Topanga Creek. Black triangles depict Lower Topanga samples and gray circles depict Upper Topanga

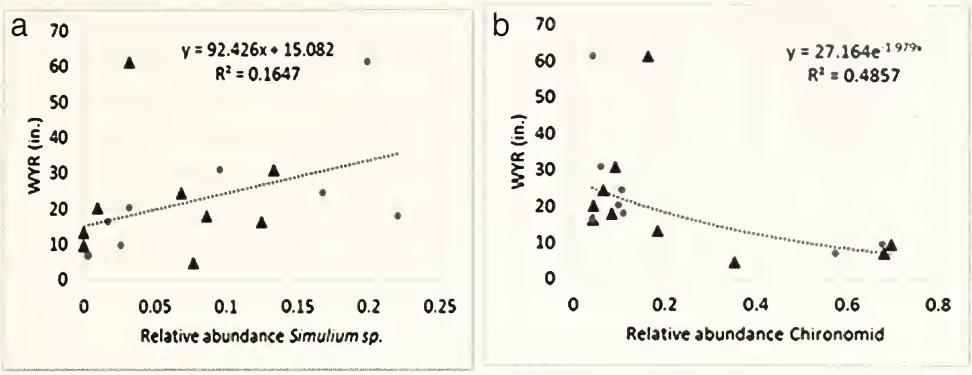

Fig. 5. (a) Relative abundance of *Simulium sp.* and wet year rainfall in Topanga Creek (b) Relative abundance of Chironomidae n.d. and wet year rainfall in Topanga Creek. Black triangles depict Lower Topanga samples and gray circles depict Upper Topanga.

any FFG group. In regional samples, only Solstice Creek also showed a significant and positive correlation between *Baetis sp.* RA and WYR (R^2=0.60, $F_{1,5}$=7.38, $p<0.05$; Fig. 6).

Abundance per sq. ft. for eight dominant taxa was compared to observed algae cover in both reaches from 2007-2014. *Baetis sp.* and *Simulium sp.* were found to positively and significantly correlated to percent algae cover (R^2=0.77, $F_{1,9}$=29.9, $p<0.0005$, R^2=0.69, $F_{1,9}$=19.6, $p<0.005$; Fig. 4b.). Multiple regression analysis was run to examine the relationship between *Baetis sp.* abundance per sq. ft. and WYR, algae, and Chironomidae n.d.. Rainfall and algae remained significant predictors of *Baetis sp.* ($p<.0005$, $p<.05$). When controlling for rain and algae, Chironomid n.d. abundance per sq. ft. was also a significant predictor of *Baetis sp.* abundance ($p<.0005$).

SCC-IBI Analysis

The Southern California Coastal Index of Biotic Integrity (SCC-IBI; Ode et al. 2005) was applied to determine if the marked change in taxonomic composition resulted in decreased scores of biotic integrity in 2013-2014. Three out of ten samples from Lower Topanga and five out of eight samples from Upper Topanga had >500 individuals and were sub-sampled to 500 individuals appropriate for SCC-IBI scoring. LT04 (n=464) was also included in SCC-IBI analysis. Overall, there was no significant correlation between total SCC-IBI scores and wet year rainfall or other creek conditions (Table 1). SCC-IBI scores ranged from 22-57, categorized as 'poor' to 'fair.' The lowest metric score across all samples was % intolerant individuals, which never surpassed a score of 1. Conversely, the highest metric on average was % tolerant taxa (average score of 6).

Discussion

Drought is a defining feature of many ecosystems including those within Mediterranean climates, and it is predicted that droughts will become more frequent and intense over the next few decades (Houghten et al. 1995). Severe drought is known to affect BMI assemblages and result in alterations to community composition (Resh et al. 2012). The current drought in Southern California is the most severe on record (NOAA 2014). While these conditions cause concern for the integrity of freshwater ecosystems, they also provide an opportunity to study potential implications of climatic patterns on freshwater benthic macroinvertebrate communities. In

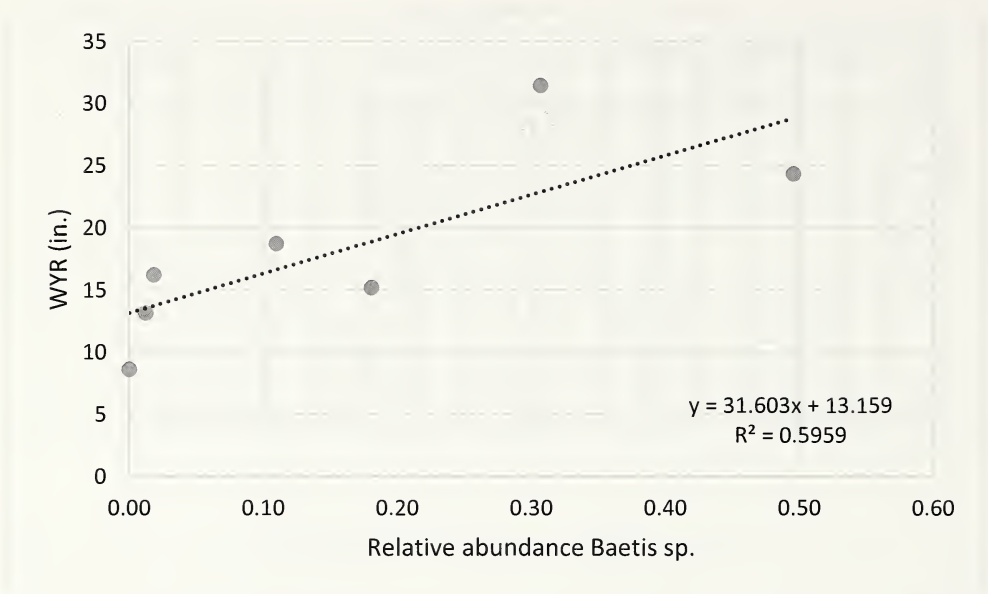

Fig. 6. Relative abundance of *Baetis sp.* compared to wet year rainfall in Solstice Creek.

2013, the Topanga Creek BMI community experienced a sharp decline in *Baetis sp.* and *Simulium sp.* abundance, and increase in Chironomidae n.d.. Each of these taxa abundance correlated to WYR, suggesting a strong relationship between annual precipitation and BMI community composition in Topanga Creek. This correlation also held true for another Santa Monica Mountains stream, Solstice Creek.

For *Simulium sp.* in Topanga Creek, the correlation to rainfall did not hold up in the case of above average rainfall (155.5 cm), and in fact all taxa appeared to diverge from the linear trend under these high rainfall conditions. This might be due to discharge rates high enough to displace certain BMI taxa. Both *Baetis sp.* and *Simulium sp.* also positively correlated to algae cover in April and May. When available, algae can be a preferred food source for Ephemeroptera, resulting in more robust growth and gill size (Mayer and Likens 1987, Gupta et al. 1994).

Chironomidae n.d. relative abundance was favored in low rainfall conditions. Multiple regression analysis showed that *Baetis sp.* and Chironomidae n.d. abundance per sq. ft. was significantly related when rainfall and algae were held constant, however this was not evident in a direct comparison. This indicates that there is a distinct relationship between *Baetis sp.* and Chironomidae n.d. that is mediated by abiotic and biotic factors such as precipitation and algal productivity. This relationship might hinge on competition for food or habitat, or sedimentation dynamics. Angradi et al. (1999) found that Ephemeroptera taxa richness is reduced when fine sediments accumulate, while some genus of Chironomidae, particularly burrowers or sediment case-makers, increase. Frost et al. (1995) affirms that changes in the abundance of one species can lead to disproportionate response from other species. Krug et al. (2012) found that both Diptera and Ephemeroptera larva are important food sources for endangered southern steelhead trout (*Oncorhynchus mykiss*), occurring in 69% and 92% of 13 stomach samples collected in Topanga Creek in March 2011. Continued monitoring is recommended to measure the resiliency of *Baetis sp.* and *Simulium sp.* under future rain conditions.

Both *Baetis sp.* and Chironomidae n.d. are classified as collector-gatherers with a tolerance value of 6 (Ode 2003). Despite changes in community demographics, trophic structure can

Table 1. Topanga Creek SCC-IBI metrics and creek conditions 2003-2014.

Sample ID	(n)	%CF+CG	% Non-Insect taxa	% Tolerant taxa	Coleoptera taxa	Predator taxa	% Intolerant	EPT taxa	SUM (0-70)	SUM (0-100)	Flow (cfs)	Mean depth (in)	Water temp (°C)	DO %	WY Rainfall (in.)
UT03	500	1	8	10	4	1	0	2	26	37	0.43	3.9	14.7	90	17.92
LT04	464	5	8	4	4	8	1	1	31	44	ND	ND	ND	ND	13.16
LT05	500	3	3	8	0	1	0	1	16	23	0.16	9.8	17	65	61.22
UT05	500	0	5	8	4	0	1	5	23	33	0.34	ND	15.1	69	61.22
UT06	500	1	5	5	4	2	0	8	25	36	0.15	11.3	15.6	100	20.04
LT07	500	5	7	7	7	4	0	10	40	57	0.05	8.7	ND	ND	4.61
UT10	500	2	8	6	2	5	1	5	29	41	1.13	9.3	10	ND	24.32
LT14	500	4	2	2	2	6	1	2	19	27	0.06	2.2	14.9	76	6.85
UT14	500	1	4	3	5	0	0	2	15	21	ND	9.6	6.85	72	6.85

remain stable (Beche et al. 2009; Vannuchi et al. 2013). This occurred to some extent in Topanga Creek, as functional feeding group distribution was less variable than species composition over time. Collector-gatherers made up the far majority, which is typical in riparian lower reaches (Hawkins et al 1981). The shift in community was accompanied by a simplification of FFG array. The decline of collector-filterer abundance correlated to *Simulium sp.* declines, indicating *Simulium sp.* was a significant collector-filterer in both the Upper and Lower Reach of Topanga Creek.

Although Topanga Creek is facing impacts of drought, it remains an important reference stream and continues to provide crucial habitat to wildlife. Catastrophic shifts in BMI community compositions have been observed to occur from stable to alternate states, sometimes irreversibly (Scheffer et al. 2001; Beche et al. 2009). In other cases, communities have rebounded within 1-3 years post-drought (Boulton 2003). How the aquatic and riparian zone insectivorous wildlife of Topanga Creek respond to the replacement of *Baetis sp.* with Chironomid n.d. and other changes among the BMI community are currently unreported. Continued long-term monitoring of BMI will support regional advances in understanding species composition trends and how they are influenced by climatic disturbances such as drought.

Conclusions

Long-term BMI monitoring is important in Topanga Creek, and other drought-affected freshwater ecosystems, to determine the influence of climatic events on taxonomic composition. In this study, drought intensification aligned with declines in *Baetis sp.* and *Simulium sp.* relative abundance. Algae presence also influenced the abundance of these two taxa, although there was no notable trend between rainfall and algae found in this study. Long-term data sets will enable scientists to track what components of BMI composition are constantly in flux, responding to biotic and abiotic processes and events, and which are perennially resilient up to the point at which catastrophic events may induce long-term disturbance within the established community. Future work in this watershed should focus on the potential recovery response of *Baetis sp.* post-drought.

Acknowledgements

This study was made possible by funding from the office of LA County Supervisor Zev Yaroslavsky, dedicated work by the Resource Conservation District of the Santa Monica Mountains Stream Team, AmeriCorps Watershed Stewards Project members Kayti Christianson, Carrie Fong, David Gottesman, Diana LaRiva, Tessa Reeder, and volunteers Uriel Cobain, Allie Irwin, Monica Jarquin, Ariane Jong, Matt Kirby, Gabby Njm, Robert Ruzicka, Vanessa Thulsiraj, Karen Vu, Sylvia Zamudo, Amy Zimmer-Faust, Mark Ziman. Dan Pickard, CDFW and Ethan Bell, Stillwater Sciences provided additional help. Finally, thanks to CA Department of Parks and Recreation for their efforts to preserve and protect Topanga Creek.

Literature Cited

Angradi, T.R. 1999. Fine sediment and macroinvertebrate assemblages in Appalachian streams: a field experiment with biomonitoring applications. Journal of North American Benthological Society, 16(1):49–66.

Bêche, L.A., P.G. Connors, V.H. Resh, and A.M. Merenlender. 2009. Resilience of fishes and invertebrates to prolonged drought in two California streams. Ecography, 32:778–788.

Boutlon, A.J., C.G. Peterson, N.B. Grimm, and S.G. Fisher. 1992. Stability of an Aquatic Macroinvertebrate Community in a Multiyear Hydrologic Disturbance Regime. Ecology, 73:2192-2207.

Boulton, A.J. 2003. Parallels and contrasts in the effects of drought on stream macroinvertebrate assemblages. Freshwater Biology, 48:1173–1185.

Bray, R.J., and J.T. Curtis. 1957. An ordination of the upland forest communities of Southern Wisconsin. Ecological Monographs, 27:325–349.

CDFG. 2003. California Stream Bioassessment Procedure: Protocol Brief for Biological and Physical Habitat Assessment in Wadeable Streams. California Department of Fish and Game Aquatic Bioassessment Laboratory, Water Pollution Control Laboratory. Retrieved September 1, 2014 from www.epa.gov/region9/qa/pdfs/csbp_2003.pdf.

CDFW. 2014. Aquatic Bioassessment Laboratory (ABL) Digital Reference Collection. Retrieved August 20, 2014 from www.dfg.ca.gov/abl/Lab/california_referencecollection.asp.

Covich, A.P., M.A. Palmer, and T.A. Crowl. 1999. The Role of Benthic Invertebrate Species in Freshwater Ecosystems. BioScience, 49:119–127.

Fetscher, A. E., L. Busse, and P.R. Ode. 2009. Standard Operating Procedures for Collecting Stream Algae Samples and Associated Physical Habitat and Chemical Data for Ambient Bioassessments in California: Retrieved September 9, 2014 from www.waterboards.ca.gov/water_issues/programs/swamp

Frost, T.M., S.R. Carpenter, A.R. Ives, and T.K. Kratz. 1995. Species compensation and complementarity in ecosystem function. Pp. 224–39 in Linking species and ecosystems (Jones, C.G., and J.H. Lawton, eds.). New York: Chapman and Hall.

Griswold, M. W., R.W. Berzinis, T.L. Crisman, and S.W. Golladay. 2008. Impacts of climatic stability on the structural and functional aspects of macroinvertebrate communities after severe drought. Freshwater Biology, 53:2465–2483.

Gupta, A., S. Gupta, and R.G. Michael. 1994. Seasonal abundance and diet of *Cloeon sp.* (Ephemeroptera: Baetidae) in a northeast Indian Lake. Archaeological Hydrobiology, 130(3):349–357.

Harrington, J. 1996. *California Stream Bioassessment Procedures*. Rancho Cordova, CA: California Department of Fish and Game, Water Pollution Control Laboratory.

Hawkins, C.P., and J.R. Sedell, 1981. Longitudinal and seasonal changes in the functional organization of macroinvertebrate communities in four Oregon streams. Ecology, 62:387–397.

Houghton, J.T., L.G.M. Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell. 1995. The Science of Climate Change, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 572 pp.

Iverson, T.M., P.W. Wiberg-Larsen, S. Hansen, and F.S. Hansen. 1978. The effect of partial and total drought on the macroinvertebrate communities of three small Danish streams. Hydrobiologia, 60(3):235–242.

Kaller, M.D., and K.J. Hartman. 2004. Evidence of a threshold level of fine sediment accumulation for altering benthic macroinvertebrate communities. Hydrobiologia, 518:95–104.

Krug, M.J., E. Bell, and R. Dagit. 2012. Growing up fast in a small creek: diet and growth of a population of *Oncorhynchus mykiss* in Topanga Creek, California. California Fish and Game, 98(1):38–46.

Lake, P.S. 2003. Ecological effects of perturbation by drought in flowing waters. Freshwater Biology, 48:1161–1172.

Lake, P. S. 2011. Drought and Aquatic Ecosystems: Effects and Responses. John Wiley & Sons, Ltd, Chichester, UK.

Mayer, M.S., and G.E. Likens. 1987. The importance of algae in a shaded headwater stream as food for an abundant caddisfly (Trichoptera). Journal of the North American Benthological Society, 6:262–269.

Merritt, R.W., K.W. Cummings, Berg, M.B. eds. 2008. An Introduction to the Aquatic Insects of North America. Kendall Hunt. Dubuque, Iowa.

NOAA. 2014. California Facing Worst Drought on Record. Retrieved January 29, 2014 from www.climate.gov/news-features/event-tracker/california-facing-worst-drought-record

Ode, P.R. 2003. CAMLnet: list of California macroinvertebrate taxa and standard taxonomic effort. Aquatic Bioassessment Laboratory, Rancho Cordova. Retrieved September 10, 2014 from http://www.safit.org/ste.html.

Ode, P.R., A.C. Rehn, and J.T. May. 2005. A quantitative tool for assessing the integrity of southern California coastal streams. Environmental Management, 35:493–504.

Ode, P.R. 2007. Standard Operating Procedures for collecting Macroinvertebrate Samples and Associated Physical and Chemical data for Ambient Bioassessments in California. SWAMP Bioassessment Procedures. Retrieved September 8, 2014 from www.waterboards.ca.gov/water_issues/swamp.

Peck, D. V., J. M. Lazorchak, and D. J. Klemm, eds. 2004. Environmental Monitoring and Assessment Program-Surface Waters: Field Operations and Methods for Measuring the Ecological Condition of Wadeable Streams. EPA/620/R-94/004F. US Environmental Protection Agency, Washington, DC.

Resh, V.H., L.A. Bêche, J.E. Lawrence, R.D. Mazor, E.P McElravy, A.P. O'Dowd, D. Rudnick, and S.M. Carlson. 2012. Long-term population and community patterns of benthic macroinvertebrates and fishes Northern California Mediterranean-climate streams. Hydrobiologia. DOI 10.1007/s10750-012-1373-9.

Scheffer, M., D. Straile, E. H. Van Nes and H. Hosper, 2001. Climate warming causes regime shifts in lake food webs. Limnology and Oceanography, 46:1780–1783.

US Census Bureau. 2010. State & County QuickFacts. Retrieved September 8, 2014 from http://quickfacts.census.gov/qfd/states/06/0678960.html

U.S. Drought Monitor Map Archive. The National Drought Mitigation Center. Lincoln, Nebraska. Retrieved August 1, 2014 from http://droughtmonitor.unl.edu/

Vannuchi, P., M. Lopez-Rodriguez, J. Tierno de Figueroa and E. Gaino. 2013. Structure and Dynamics of a Benthic Trophic Web in a Mediterranean Seasonal Stream. Journal of Limnology, 72:606–615

Vieira, N.K.M., N.L. Poff, D.M. Carlisle, S.R. Moulton, M.L. Koski, and B.C. Kondratieff. 2006. A database of lotic invertebrate traits for North America: U.S. Geological Survey Data Series 187, http://pubs.water.usgs.gov/ds187.

Voshell, J.R. 2002. A Guide to Common Freshwater Invertebrates of North America. McDonald and Woodward Publishing Company.

Wright, J.F., and K.L. Symes. 1999. A nine-year study of the macroinvertebrate fauna of a chalk stream. Hydrological Processes, 13:371–385.

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The Bigeye Scad, *Selar crumenophthalmus* (Bloch, 1793) (Family Carangidae), New to the California Marine Fauna, with a List to and Keys for All California Carangids

Milton S. Love,[1]* Julianne Kalman Passarelli,[2] Chris Okamoto,[2] and Dario W. Diehl[3]

[1]*Marine Science Institute, University of California, Santa Barbara, CA 93106*
[2]*Cabrillo Beach Marine Aquarium, 3720 Stephen M White Dr, San Pedro, CA 90731*
[3]*Southern California Coastal Water Research Project, 3535 Harbor Blvd., Suite 110, Costa Mesa, CA 92626*

The anomalously warm waters of the northeast Pacific 2014–2015 brought with it a variety of subtropical and tropical fish species previously unusual or absent from California waters (Bond et al., 2015; pers. comm. M. McCrea, pers. comm.; J. Shepherd). On 1 February 2015, Mr. Keichi Yamamoto speared a fish that we have identified as *Selar crumenophthalmus* (Bloch, 1793), the bigeye scad (Fig. 1). The fish was captured in the midwaters of a kelp bed (bottom depth 8 m) off Rancho Palos Verdes (33°48′N, 118°24′W), southern California. This is the first time this species has been reported from off California. The fish he speared was one of approximately 10 conspecifics that were swimming with a school of juvenile jack mackerel, *Trachurus symmetricus* (Ayres, 1855). This specimen is housed in the fish collection at the Natural History Museum of Los Angeles County, LACM 58288-1.

We identified this fish (22.4 cm fork length) through the following diagnostic characters: Two papillae on the bone margin at the rear of the gill chamber (the lower one larger than the upper); the presence of a large eye (eye width greater than snout length) with adipose eyelid covers; and dorsal, anal, and pectoral fin counts and gill raker counts (Table 1). Meristics from our specimen fall within the range reported by other studies. Hardened scutes were present in the posterior lateral line. No finlets were present. The fish color was olive on dorsum, with a golden stripe along flanks, and a silvery belly. There was a diffuse golden ring around the eye.

Bigeye scad are normally circumtropical. In the western Pacific, they have been found as far northward as the Pacific coast of southern Japan (Nakabo, 2002) and Sea of Japan (Parin, 2003). Previous to this capture, the eastern Pacific range was from Lagunas Ojo de Liebre-Guerrero Negro, central Baja California (Galván-Magaña et al., 2000) to Cabo Blanco, Peru (Chirichigno, 1974), including the Gulf of California (Smith-Vaniz in Fischer et al., 1995), Islas Galápagos (Grove and Lavenberg, 1997), Isla de Malpelo, Isla de Coco, Isla Clipperton, and Islas Revillagigedo (Robertson and Allen, 2008). This is a pelagic species found from surface waters to depths of 170 m (558 ft) (Randall et al., 1990, Allen and Robertson, 1994). It reaches a maximum length of 70 cm (Kuiter and Tonozuka, 2001).

Of particular interest is that Mr. Yamamoto first observed a similar number of what were likely the same species in the same location in November 2014, also mixed in with juvenile jack mackerel. In addition, Mr. Yamamoto continued to observe bigeye scad at this location to as late as early March 2015, at this time swimming with a school of juvenile Pacific barracuda (*Sphyraena argentea* Girard, 1852). These sightings suggest that at least some bigeye scad may remain within a relatively circumscribed area for lengthy periods.

* Corresponding author: love@lifesci.ucsb.edu

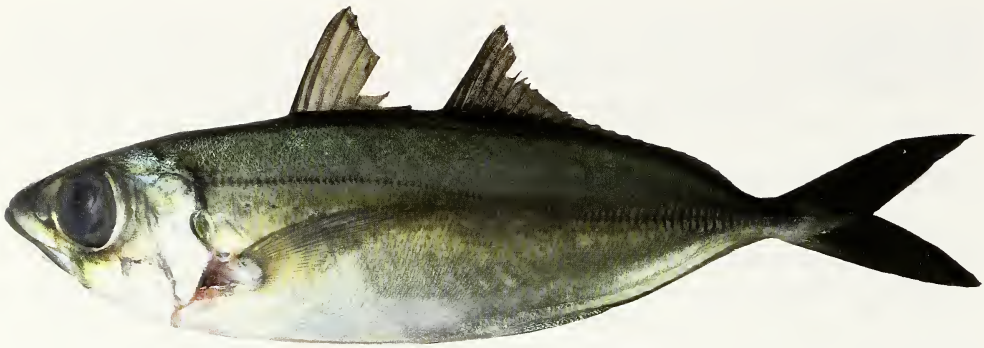

Fig. 1. A bigeye scad, *Selar crumenophthalmus* (Bloch, 1793), taken on 1 February 2015, off Rancho Palos Verdes (33°48′N, 118°24′W), southern California. Catalogued in the Los Angeles County Museum of Natural History as LACM 58288-1.

The addition of the bigeye scad to the California marine fauna brings the total number of jack species taken from these waters to 16 (Table 2). The last key to the California species (Miller and Lea, 1972) was based on 13 species and we include a new key to all known California species, using the key to eastern Pacific species created by W. F. Smith-Vaniz in Fischer et al. (1995) as a starting point. We note that this new key was tested on individuals of all carangids found in California waters. In addition to the California species, we have also included in the key the Japanese amberjack, *Seriola quinqueradiata* Timminck & Schlegel, 1845. In 2015, this species was found inside the wreckage of a Japanese vessel destroyed in the Fukishima tsunami that had floated to the Oregon coast (J. Burke, pers. comm.) raising the possibility of future captures off California. In addition, this species is often sold in California fish markets and in our experience this has led enforcement officers to confuse it with the eastern Pacific species, the yellowtail, *Seriola dorsalis* Gill (1863).

Key to the California Carangidae

1a Head profile strongly oblique; very small, embedded scales, leading to apparently naked body; very compressed body in adults 2
1b Head profile not strongly oblique; no embedded scales; moderately compressed body in adults 3
2a Oblique head profile has a slight concavity in front of eyes; small juveniles with an oval black spot above the straight portion of the lateral line: . . . . . *Selene peruviana*
2b Oblique head profile lines nearly straight in front of eyes; small juveniles with 4 or 5 interrupted dark vertical stripes on the body: . . . . . *Selene brevoortii*
3a *From 1b: Head profile not strongly oblique…*
Posterior straight part of lateral line with hardened scutes or bony shields, scutes can be poorly developed 4
3b Posterior straight part of lateral line without scutes (only pored scales, not enlarged) 12

Table 1. Meristics of bigeye scad, *Selar crumenophthalmus* (Bloch, 1793) from this study, Moser et al. (1996), Nakabo (2002), and Robertson and Allen (2015).

Source	Dorsal fin	Anal fin	Pectoral fin	Gill rakers 1st arch
This study	VIII+I,27	II+I,23	23	11+27[1]
Moser et al. (1996)	VIII+I,24–27	II+I,20–23	19–23	9–12+27–37
Nakabo (2002)	VIII+I,23–28	II+I,21–23		9–12+24–31
Robertson and Allen (2015)	VIII+24–27	II+I,21–23		9–12+27–37

[1] Counts from right arch as left gill arches were lost during capture.

Table 2. Members of the family Carangidae that are known from California waters, with notes on their maximum sizes, and geographic and depth ranges.

Caranx caballus Günther, 1868. Green Jack. To at least 70 cm TL (Allen and Robertson 1994). Monterey Bay, central California (Lea and Walker 1995) to Chile (Pequeño 1989), including Gulf of California (Robertson and Allen 2002), Islas Galápagos (Miller and Lea 1972), and Hawaii (Randall and Carlson 1999). Surf zone and to 100 m (min.: Carlisle et al. 1960; max.: De La Cruz-Agüero et al. 1997). D VIII + I,21–25; A II + I,17–24; Pect. 20; LL scutes 45–56; GR 13–16 + 25–32; Vert. 25. Recently as *Carangoides caballus* (Randall 2007).

Caranx caninus Günther, 1867. Pacific Crevalle Jack. To 100 cm TL (Smith-Vaniz in Fischer et al. 1995). Warm waters of eastern Pacific; Huntington Beach, southern California (Miller and Curtis 2008) to Iquique, northern Chile (Sielfeld et al. 2010), including Gulf of California (Robertson and Allen 2002), Islas Galápagos (Grove and Lavenberg 1997), and other offshore islands (Robertson and Allen 2002). Surface to 350 m (Smith-Vaniz in Fischer et al. 1995). D VII–VIII + I,18–23; A II+I,15–18; Pect. I,18–21; LL shields 25–42; GR 15–19 on lower limb; Vert. 24. Some previous records report this as *Caranx hippos*; however that species is now considered a separate Atlantic and Caribbean taxa.

Caranx sexfasciatus Quoy & Gaimard, 1825. Bigeye Trevally. To 120 cm TL (Sadovy and Cornish 2000). Pacific and Indian oceans; southern Japan (Nakabo 2002); San Diego Bay, southern California (Lea and Walker 1995) to northern Peru (Robertson and Allen 2015), including lower Gulf of California (Robertson and Allen 2002) and Islas Galápagos (Grove and Lavenberg 1997). Shallow, near reefs (Moser 1996), 1–96 m (min.: González-Acosta et al. 1999; max.: Myers 1999). D VII–VIII + I,19–22; A II + I,14–17; Pect. 18–21; Pelvic I,5; GR 4–8 + 15–19; Vert. 25.

Caranx vinctus Jordan & Gilbert, 1882. Cocinero. To 38 cm TL (Amezcua Linares 1996). San Diego Bay, southern California (Lea and Rosenblatt 2000) to Tumbes, Peru (Chirichigno and Vélez 1998), including central and southern Gulf of California (Robertson and Allen 2002). Surface to 50 m (De La Cruz-Agüero et al. 1997). D VII–VIII + I,22–24; A II+I,18–21; Pect. 19; GR 11–12 + 28–30; Vert. 25. Also recently as *Carangoides vinctus* (Angulo et al. 2013).

Chloroscombrus orqueta Jordan & Gilbert, 1883. Pacific Bumper. To 31 cm SL [about 38.8 cm TL) (Amezcua Linares 1996). San Pedro, southern California (Miller and Lea 1972) to Chilca, Peru (Beltrán-León and Rios Herrera 2000), including Gulf of California (Smith-Vaniz in Fischer et al. 1995) and Isla Malpelo (Robertson and Allen 2002). Shallow coastal waters and estuaries (Moser 1996) to 53 m (Zeballos 1998). D VII–VIII + I,26–30; A II + I,25–30; Pect. 19–21; Pelvic I,5; LL shields nearly obsolete, less than 20; GR 8–10 + 30–37; Vert. 24.

Decapterus muroadsi (Temminck & Schlegel, 1844). Amberstripe Scad. To about 55 cm TL (Robertson and Allen 2002). Warm waters of Pacific; Japan to East China Sea (Masuda et al. 1984); Pacific Grove, central California (Miller and Lea 1972) to Peru (Moser 1996), Easter Island (Pequeño 1989), and Islas Galápagos (Grove and Lavenberg 1997); apparently not in Gulf of California (Robertson and Allen 2002). Surface to 320 m (Mundy 2005). D VII+VIII + I,29–33 + finlet; A II + I, 25–29 + 1 finlet; Pect. 22–23; LL enlarged shields about 30; GR 13–16 + 37–42; Vert. 24. Includes *Decapterus hypodus* Gill, 1862, and *Decapterus scombrinus* (Valenciennes, 1846) as junior synonyms.

Naucrates ductor (Linnaeus, 1758). Pilotfish. To 70 cm TL (Smith-Vaniz in Fischer et al. 1995). Circumglobal; in western Pacific as far north as Japan (Nakabo 2002) and southern Kuril Islands (Savinykh 1998); Vancouver Island, British Columbia (Eschmeyer and Herald 1983) to Chile (Pequeño 1989), including Gulf of California (Smith-Vaniz in Fischer et al. 1995) and such offshore islands as Islas Galápagos (Miller and Lea 1972). Surface to 150 m (Robertson and Allen 2002). D III–VI + I,24–29; A I–II + I,15–18; Pect. 18–20; Pelvic I,5; GR 5–8 + 12–19 = 18–26; Vert. 25.

Selar crumenophthalmus (Bloch, 1793). Bigeye Scad. To 70 cm (Kuiter and Tonozuka. 2001). Circumglobal; Pacific coast of southern Japan (Nakabo 2002) and Sea of Japan (Parin 2003); Palos Verdes, southern California (this paper) to Cabo Blanco, Peru (Chirichigno 1974), including Gulf of California (Smith-Vaniz in Fischer et al. 1995) and Islas Galápagos (Grove and Lavenberg, 1997), Isla de Malpelo, Isla de Coco, Isla Clipperton, and Islas Revillagigedo (Robertson and Allen, 2008). Surface to 170 m (min.: Allen and Robertson 1994; max.: Randall et al. 1990). D VIII + I,23–28; A II + I, 20–23; Pect. 19–23; GR 9–12 + 24–37; Vert. 24.

Table 2. Continued.

Selene brevoortii (Gill, 1863). Mexican Lookdown. To 42 cm TL (Robertson and Allen 2002). Seal Beach, southern California (Jarvis et al. 2009) to northern Chile (Sielfeld et al. 2010), including Gulf of California (Smith-Vaniz in Fischer et al. 1995). Coastal waters, including bays and estuaries (Moser 1996), to 50 m (Robertson and Allen 2002). D VII–VIII + I,20–24; A II + I,17–19; Pect. 18–19; GR 5–9 + 28–34; Vert. 24.

Selene peruviana (Guichenot, 1866). Pacific Moonfish. To variously between 35 cm TL (Velasco and Thiel 2002) and 85 cm TL (Franke and Acero 1993). Long Beach, southern California (Miller and Lea 1972) to Chile (Pequeño 1989), including Gulf of California (Smith-Vaniz in Fischer et al. 1995) and Islas Galápagos (Grove and Lavenberg 1997). Inshore (Grove and Lavenberg 1997) and shallow coastal waters (Moser 1996) to 450 m (Franke and Acero 1993). D VIII + I,20–24; A II + I,16–19; LL shields nearly obsolete; GR 8 + 28–32; Vert. 24.

Seriola dorsalis Gill (1863). Yellowtail. To at least 1.5 m (5 ft) TL (Miller and Lea 1972). In eastern Pacific from northern British Columbia (54°35′N, 31°00′W; Nagtegaal and Farlinger 1981) to central Mexico (Robertson and Allen 2015), including Gulf of California (Miller and Lea 1972), Islas Galápagos (Grove and Lavenberg 1997), and Isla Malpelo (Robertson and Allen 2002). Unverified reports from Gulf of Alaska off Kodiak Island and Cordova (Mecklenburg et al. 2002). Primarily epipelagic, recorded from surface to at least 91 m (300 ft) (min.: Miller and Lea 1972; max.: N. Ben-Aderet, pers. comm.). Individuals from the eastern Pacific have recently been referred to as the widely distributed *Seriola lalandi* Valenciennes, 1833. However, we follow Martinez-Takeshita et al. (2015) and limit the distribution of *S. lalandi* to the Southern Hemisphere, resurrecting *S. aureovittata* Temminck & Schlegel (1845) in the northeast Pacific, and *S. dorsalis* in the eastern Pacific. D IV–VII + I,29–39; A O–II + I,19–25; Pect. 19–20; Pelvic I,5; GR 5–10 + 15–22; Vert. 25.

Seriola rivoliana Valenciennes, 1833. Almaco Jack. To 160 cm FL [about 176 cm TL] (IGFA). Circumglobal; Korea (Kim et al. 1997) and southern Japan (Nakabo 2002); Oceanside, southern California (Eschmeyer and Herald 1983) to Cabo Blanco, Peru (Chirichigno and Vélez 1998), including Gulf of California (Smith-Vaniz in Fischer et al. 1995) and Islas Galápagos (Eschmeyer and Herald 1983). Pelagic, at depths of 1–250 m (min.: Kuiter and Tonozuka 2001; max.: Robertson and Allen 2002). D VIII + I,26–33; A II + I,18–21; Pect. 19–22; LLs 167; GR 6–9 + 16–19 = 22–28; Vert. 24.

Trachinotus paitensis Cuvier, 1832. Paloma Pompano. To 50.8 cm TL (Miller and Lea 1972). Redondo Beach, southern California (Miller and Lea 1972) to Chile (Pequeño 1989), including Gulf of California and Islas Galápagos (Miller and Lea 1972). Shallow inshore areas (Miller and Lea 1972) and to 100 m (Amezcua Linares 1996). D VI–VIII,20–27; A II+I (occasionally III),20–24; Pect. 16–18; Pelvic I,5; GR 9–11 + 11–17; Vert. 24.

Trachinotus rhodopus Gill, 1863. Gafftopsail Pompano. To 61 cm TL (Miller and Lea 1972). Zuma Beach, southern California (Miller and Lea 1972) to Callao, Peru (Chirichigno and Vélez 1998), including southern and central Gulf of California (Robertson and Allen 2002) and Islas Galápagos (Miller and Lea 1972). Surface to 30 m (min.: Robertson and Allen 2002; max.: Amezcua Linares 1996). D V–VI + I,19–21; A II + I,17–21; Pect. 18–19; Pelvic I,5; GR 8–10 + 13–16 = 21–26; Vert. 24.

Trachurus symmetricus (Ayres, 1855). Jack Mackerel. To 81.3 cm TL (Miller and Lea 1972). Pacific Ocean south of Aleutian Islands (Mecklenburg et al. 2002 [UW 15469]) and in Gulf of Alaska to Gulf of California (Smith-Vaniz in Fischer et al. 1995) and to Acapulco, Mexico (Palacios-Salgado et al. 2014). Primarily pelagic, surface (Miller and Lea 1972) from surf zone (Carlisle et al. 1960) and offshore to 403 m (Hart 1973). Although *Trachurus murphyi* Nichols, 1920, found off South America, is considered by some authors (e.g., Grove and Lavenberg 1997) to be a subspecies of *T. symmetricus*, DNA evidence indicates it is a separate species (Poulin et al. 2004). D VIII + I,28–38; A II + I,22–33; Pect. 21–24; Pelvic I,5; LLs 87–111, the later 40–55 as enlarged shields; GR 7–15 + 25–42 = 32–57; Vert. 23–25.

Uraspis helvola (Forster, 1801). Whitemouth Jack. To 58 cm TL (Jiménez Prado and Béarez 2004). Indo-Pacific; perhaps southern Kuril Islands (Savinykh and Shevtsov 2001) and southern Japan (Nakabo 2002); Santa Catalina Island, southern California (Miller and Lea 1972), southernmost Gulf of California (J. Snow, pers. comm.), and at a number of more southerly locations (Robertson and Allen 2015) to Ecuador (Béarez 1996), including Islas Galápagos (Grove and Lavenberg 1997). 10–300 m (Robertson and Allen 2002). D V–VIII + I,25–30; A II + I,19–22; Pect. I,22; LL with 32–38 keeled shields; GR 6 + 16 = 22. The Santa Catalina Island specimen was originally identified as *Uraspis secunda* (Fitch 1972). However, *U. secunda* appears to be an Atlantic and Indo-Central Pacific species (W. Smith-Vaniz and R. Robertson, pers. comms. to M. L.).

4a Lateral line with reduced (very stunted), barely perceptible scutes; a black spot on the saddle of the upper region of the caudal peduncle; strongly compressed body:. . . . . *Chloroscombrus orqueta*

4b Well-developed lateral line scutes; caudal peduncle without black spot; body not strongly compressed 5

5a Dorsal accessory branch of the lateral line extends at least to below origin of 2nd dorsal fin, usually farther posteriorly:. . . . . *Trachurus symmetricus*

5b Dorsal accessory branch of the lateral line terminating before origin of dorsal fin. 6

6a Independent 2-rayed finlet at caudle peduncle (dorsal and ventral): . . . . .*Decapterus muroadsi*

6b Second dorsal and anal fins without finlets 7

7a Cleithrum, under the operculum, with a furrow (groove) on the ventral side, a large papilla-like structure immediately above the groove; eye nearly covered by an adipose eyelid, forming a vertical slit on the center of the pupil:. . . . . .*Selar crumenophthalmus*

7b Smooth-edge cleithrum; adipose eyelid marginally covering eye but not pupil 8

8a Tongue, roof, and floor of mouth white, the rest black; no teeth on vomer or palatines: . . . . . .*Uraspis helvola*

8b Lining of mouth not distinctly black and white; teeth present on vomer and palatines. 9

9a Breast without scales except for a small patch of scales at base of pelvic fins (prepelvic): . . . . . *Caranx caninus*

9b Breast completely scaled. 10

10a Number of scutes in the lateral line 26–42; total number of gill rakers on the lower limb (including rudiments) 15–22; lobe of second dorsal fin with a white tip and its height into fork length 5.0 to 6.6 times in adults:. . . . . *Caranx sexfasciatus*

10b Number of scutes in the lateral line 42–56; total number of gill rakers on the lower limb (including rudiments) 27–30; lobe of second dorsal fin without white tip and its height into fork length 6.0 to 8.0 times in adults. 11

11a In adults, body without dark vertical stripes; scaly basal sheath along the lobes of the dorsal and anal fins with relatively narrow scales, above which the fins are almost entirely covered with small scales; back of the eye covered by a weak adipose eyelid extending to the rear edge of the pupil: . . . . . *Caranx caballus*

11b In adults, body with 8–9 dark incomplete vertical stripes; scaly basal sheath along the lobes of the dorsal and anal fins with relatively wide scales above which the fins are devoid of small scales; back of the eye covered by a weak adipose eyelid that does not reach the posterior edge of the pupil:. . . . . *Caranx vinctus*

12a *From 3b*: *Posterior straight part of lateral line without scutes…*
Caudal-peduncle grooves (or shallow notch) present dorsally and ventrally; base of soft dorsal and anal fins unequal in length with anal-fin base shorter (only about 45–70%) than dorsal-fin base length 13

12b Caudal-peduncle grooves absent; base of soft anal fin as long as, or only slightly shorter than, base of dorsal fin 15

13a Fleshy keel on caudal peduncle well developed; soft anal-fin rays 15–17; body with 5–6 dark vertical bars, extending to bases of dorsal and anal fins:. . . . . *Naucrates ductor*

13b Fleshy keel on caudal peduncle absent to moderately developed; soft anal-fin rays 18–22; body lacking obvious wide vertical bars. 14

14a Longest dorsal soft-ray about 1/2 length of head; relatively slender supramaxilla; caudal fin yellowish; yellow stripe along mid-body; head longer than body depth at origin of dorsal fin: . . . . . *Seriola dorsalis*

Note: *Seriola quinqueradiata* can be differentiated from *S. dorsalis* by 1) the latter's more rounded dorsoposterior corner of upper jaw (Figure 2) and 2) a pectoral fin shorter than pelvic fin versus 1) more angular and 2) almost equal in length.

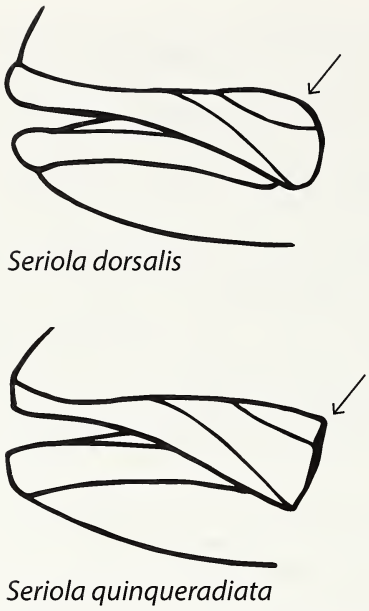

Fig. 2. An illustration comparing the upper jaw shapes of *Seriola dorsalis* and *S. quinqueradiata.* Note the more rounded dorsoposterior corner of the upper jaw of *S. dorsalis.*

14b Longest dorsal soft-ray about 2/3 length of head in fish over 18 cm fork length; relatively broad supramaxilla; caudal fin dark to dusky; black stripe radiating from mandibles, through eye, to 1st dorsal spines; head shorter than body depth at origin of dorsal fin: . . . . . .*Seriola rivoliana*

15a *From 12b*: *Caudal-peduncle grooves absent*...
First 4–5 dorsal and anal soft-rays elongated, longer than head length in fish over 8 cm fork length; in adults, 4–6 incomplete vertical bars extending beyond the lateral line; 22–26 gill rakers (8–10 on upper limb):. . . . . *Trachinotus rhodopus*

15b First 4–5 dorsal and anal soft-rays equal to or shorter than head length; in adults, no vertical bars as described above; 15–18 gill rakers (5–7 on upper limb): . . . . . *Trachinotus paitensis*

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Literature Cited

Allen, G.R. and D.R. Robertson. 1994. Fishes of the tropical eastern Pacific. University of Hawaii Press, Honolulu.

Amezcua Linares, F. 1996. Peces demersales de la platforma continental del Pacífico Central de México. Instituto de Ciencias del Mar y Limnologíca, Universidad Nacional Autónoma de México.

Angulo, A., C.A. Garita-Alvarado, W.A. Bussing, and M.I. López. 2013. Annotated checklist of the freshwater fishes of continental and insular Costa Rica: additions and nomenclatural revisions. Check List 9:987–1019.

Béarez, P. 1996. Lista de los peces marinos del Ecuador continental. Rev. Biol. Trop., 44:731–741.

Beltrán-León, B.S. and R. Rios Herrera. 2000. Estadios tempranos de peces del Pacific Colombiano. Republica de Colombia. Instituto Nacional de Pesca y Acuicultura INPA.

Bond, N.A., M.F. Cronin, H. Freeland, and N. Mantua. 2015. Causes of impacts of the 2014 warm anomaly in the NE Pacific. Geophys. Res. Letters 42, doi:10.1002/2015GL063306.

Carlisle, J.G. Jr., J.W. Schott, and N.J. Abramson. 1960. The barred surfperch (*Amphistichus argenteus* Agassiz) in southern California. Calif. Dep. Fish Game Fish Bull. 109.

Carpenter, K.E. and V.H. Niem (eds.). 1999. The living marine resources of the Western Central Pacific. Vol. 3. Batoid fishes, chimaeras and bony fishes part 1 (Elopidae to Linophrynidae). Vol. 4. Bony fishes part 2 (Mugilidae to Carangidae). FAO, Rome.

Chirichigno, F.N. 1974. Clave para identificar los peces marinos del Peru. Instituto del Mar del Peru Informe, No. 44.

Chirichigno, F.N. and J. Vélez D. 1998. Clave para identificaticar los peces marinos del Peru (segunda edición, revisada y actualizada). Instituto de Mar de Peru. Publicación Especial.

De La Cruz-Agüero, J., M.A. Martínez, V.M. Cota-Gómez, and G. De La Cruz-Agüero. 1997. Catalogo de los peces marinos de Baja California sur. Centro Interdiscipinario de Ciencias Marinas.

Eschmeyer, W.N. and E.S. Herald. 1983. A field guide to Pacific Coast fishes of North America from the Gulf of Alaska to Baja California. Houghton Mifflin, Boston.

Fitch, J.E. 1972. The cottonmouth jack, *Uraspis secunda*, added to the marine fauna of California. Calif. Fish Game, 58:245–246.

Franke, R. and A. Acero P. 1993. Peces carangoideos del Parque Gorgona, Pacifico Colombiano (Osteichthys: Carangidae, Nematistiidae y Coryphaenidae). Rev. Biol. Mar., Valparaiso, 28:51–73

Galván-Magaña, F., F. Gutiérrez-Sánchez, L.A. Abitia-Cárdenas, and J. Rodriquez-Romero. 2000. The distribution and affinities of the shorefishes of the Baja California Sur lagoons. Pp. 383–398 in Aquatic ecosystems of Mexico: status and scope. Ecovision World Monograph Series (M. Munawar, S.G. Lawrence, I. F. Munawar, and Malle, D.F. eds.). Backhuys Publisher, Leiden, The Netherlands.

González-Acosta, A.F., G. De La Cruz-Agüero, J. De La Cruz-Agüero, and G. Ruiz-Campos. 1999. Ictiofauna asociada al manglar del Estero el Conchalito, Ensenada de la Paz, Baja California Sur, México. Oceánides, 14(2):121–131.

Grove, J.S. and R.J. Lavenberg. 1997. The Fishes of the Galápagos Islands. Stanford University Press, Stanford, California.

Hart, J.L. 1973. Pacific Fishes of Canada. Fish. Res. Board Can., Bull. 180.

Jarvis, E.T., H.L. Gliniak, O. Horning, and C. Linardich. 2009. Occurrence of juvenile Mexican lookdown, *Selene brevoortii* (Gill, 1863), in Seal Beach, California. California Fish and Game, 95:188–192.

Jiménez Prado, P. and P. Béarez. 2004. Peces marinos del Ecuador continental/marine fishes of continental Ecuador. SIMBIOE/NAZCA/IFEA TOMO II. Quito.

Kim, Y.S., Y.U. Kim, and G. Ahn. 1997. First record of the carangid fish, *Seriola rivoliana* from Korea. Korean J. Ichthyol., 9:244–247.

Kuiter, R.H. and T. Tonozuka. 2001. Pictorial Guide to Indonesian Reef Fishes. Part 1. Eels–Snappers, Muraenidae–Lutjanidae. Zoonetics, Australia. 302 pp.

Lea, R.N. and R.H. Rosenblatt. 2000. Observations on fishes associated with the 1997–98 El Niño off California. CalCOFI Rep., 41:117–129.

Lea, R.N. and H.J. Walker Jr. 1995. Record of the bigeye trevally, *Caranx sexfasciatus*, and Mexican lookdown, *Selene brevoorti*, with notes on other carangids from California. Calif. Fish Game, 81:89–95.

Martinez-Takeshita, N., C.M. Purcell, C.L. Chabot, M.T. Craig, C.N. Paterson, J.R. Hyde, and L.G. Allen. 2015. A tale of three tails: cryptic speciation in a globally distributed marine fish of the genus *Seriola*. Copeia, 103(1):357–368.

Masuda, H., K. Amaoka, C. Araga, T. Uyeno, and T. Yoshino. 1984. The Fishes of the Japanese Archipelago. Tokai Univ. Press.

Mecklenburg, C.W., T.A. Mecklenburg, and L.K. Thorsteinson. 2002. Fishes of Alaska. American Fisheries Society, Bethesda, Maryland.

Miller, D.J. and R.N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Dep. Fish Game Fish Bull. 157.

Miller, E.F. and M.D. Curtis. 2008. First occurrence of a Pacific crevalle jack, *Caranx caninus*, north of San Diego, California. Bull. S. Calif. Acad. Sci., 107:41–43.

Moser, H.G. (ed.). 1996. The early stages of fishes in the California Current region. CALCOFI (California Cooperative Oceanic Fisheries Investigations) Atlas No. 33. U.S. Department of Commerce, NOAA, NMFS, Southwest Fisheries Science Center, La Jolla, California.

Mundy, B.C. 2005. Checklist of the Fishes of the Hawaiian Archipelago. Bishop Museum Press, Honolulu, Hawaii.

Myers, R. F. 1999. Micronesian Reef Fishes. Coral Graphics, Barrigada, Guam.

Nagtegaal, D.A. and S.P. Farlinger. 1981. First record of two fishes, *Seriola dorsalis* and *Medialuna californiensis*, from waters off British Columbia. Syesis 13:206–207. [Journal dated 1980 but not issued until 1981.]

Nakabo, T. (ed.). 2002. Fishes of Japan with Pictorial Keys to the Species, English edition. Tokai University Press, Tokyo.

Palacios-Salgado, D. S., A. Ramírez-Valdez, A. A. Rojas-Herrera, J. G. Amores, and M. A. Melo-García. 2014. Marine fishes of Acapulco, Mexico (eastern Pacific Ocean). Mar. Biodiv. 44:471–490.

Parin, N.V. 2003. An annotated catalogue of fish-like vertebrates and fishes of the seas of Russia and adjacent countries: Part 3. Orders Perciformes (excluding suborders Gobioidei, Zoarcoidei and Stichaeoidei) and Tetraodontiformes. J. Ichthyol. 43:S1–S40.

Pequeño R.G. 1989. Peces de Chile lista sistematica revisada y comentada. Rev. Biol. Mar. (Valparaiso) 24:1–132.

Poulin, E., L. Cardenas, C.E. Hernandez, I. Kornfield, and F.P. Ojeda. 2004. Resolution of the taxonomic status of Chilean and California jack mackerels using mitochondrial DNA sequence. J. Fish Biol. 65:1160–1164.

Randall, J. 2007. Reef and Shore Fishes of the Hawaiian Islands. Sea Grant College Program, University of Hawai'i, Honolulu.

Randall, J. and B.A. Carlson. 1999. *Caranx caballus*, a new immigrant carangid fish to the Hawaiian Islands from the tropical eastern Pacific. Pac. Sci. 53:357–360.

Randall, J., G.R. Allen, and R.C. Steene. 1990. Fishes of the Great Barrier Reef and Coral Sea. University of Hawaii Press, Honolulu.

Robertson, D.R. and G.R. Allen. 2002. Shorefishes of the Tropical Eastern Pacific: an Information System. CD-ROM. Smithsonian Tropical Research Institute, Balboa, Panama.

Robertson, D.R. and G.R. Allen. 2008. Shorefishes of the tropical eastern Pacific: an information system. Version 1.0 (2008). Smithsonian Tropical Research Institute, Balboa, Panama. www.neotropicalfish.org/sftep.

Robertson, D.R. and G.R. Allen. 2015. Shorefishes of the Tropical Eastern Pacific: an Information System. Version 2.0. Smithsonian Tropical Research Institute, Balboa, Panama. http://biogeodb.stri.si.edu/sftep/en/pages. Accessed 2 June 2015.

Sadovy, Y. and A.S. Cornish. 2000. Reef fishes of Hong Kong. Hong Kong University Press, Hong Kong.

Savinykh, V.F. 1998. Nekton composition of near-surface waters of the subarctic front zone in the northwest part of the Pacific Ocean according to the data of drift-net catches. J. Ichthyol. 38:18–27.

Savinykh, V.F. and G.A. Shevtsov. 2001. Two new species from Russian fauna from the waters of the southern Kuril Islands. J. Ichthyol. 41:122–124.

Sielfeld, W., J. Laudien, M. Vargas, and M. Villegas. 2010. El Niño induced changes of the coastal fish fauna off northern Chile and implications for ichthyogeography. Rev. Biol. Mar. Oceanog. 45, S1:705–722.

Smith-Vaniz, W. F. 1995. Carangidae. Pp. 940–986 in Guía FAO para la identificación para los fines de la pesca. Pacifico centro-oriental (Fischer, W., F. Krupp, W. Schneider, C. Sommer, K. E. Carpenter, and V. H. Niem eds.). Vol. II, Vertebrados, Parte 1. Vol. III, Vertebrados, Parte 2. FAO, Rome.

Velasco, A. and R. Thiel. 2002. A bilingual field manual for the identification of juvenile fish over soft bottom off the Pacific Coast of Colombia a review from literature. Arch. Fish. Mar. Res. 50:55–118.

Zeballos, J., M. Samame, and M. Robero. 1998. Estructura especiologica demersal observada durante el Crucero de Evaluación de la Merluza entre Puerto Pizarro y Huarmey. BIC José Olaya Balandra 9806-07. Inf. Inst. Mar Perú 138:87–100.

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A Flora of the Ballona Wetlands and Environs

E.A. Read

E Read and Associates, Inc. Orange, CA 92866, marshmistress@msn.com

A list of vascular plant taxa is provided for a study area that encompasses the current Ballona Wetlands Ecological Reserve, Ballona Freshwater Wetlands, and areas that were part of the historic Ballona Wetlands and adjacent bluffs. The flora for this area has been documented in unpublished reports and voucher collections but not compiled into a single list. A total of 407 taxa comprise this flora, of which 40% are not indigenous to California. This percentage is higher than the percentage of non-indigenous species in California as a whole (17%). Out of 242 native species reported for the study area, 26 percent (62 species) have not been observed or collected since major hydrological alterations of the watershed began in the 1930s. Restoration planned for the Ballona Wetlands Ecological Reserve offers an opportunity to re-introduce some of the historically native flora, including rare and endangered species.

The study area is located about two miles north of Los Angeles International Airport (Fig. 1). Limits of the study area were defined based on maps of the historical extent of the wetlands and adjacent uplands. Land use planning in this region has been controversial for at least 40 years, with various proposals ranging from development to restoration. With the exception of occasional botanical collections, systematic floristic surveys were not documented until Clark (1979), when a single season of field work was conducted in March and April of 1978. Subsequent floristic surveys in 1980-1981 by Gustafson (1981) and in 1990 by Henrickson (1991) covered more than one season. While these surveys were supported in part by voucher collections deposited with the Natural History Museum of Los Angeles County, results of these and subsequent surveys (Read 1995; MEC Analytical Systems 2005; Johnston 2011) were not published. This paper combines plant lists and historical collection records for the Ballona region into a single list and updates nomenclature. Historical conditions, occurrence of rare species, and occurrence of non-native invasive taxa are also discussed.

Latin nomenclature was updated based on current taxonomy (Baldwin et al. 2012). In cases of species subject to extensive taxonomic revisions, older taxonomies were used to verify identification of historical collections (Abrams 1902, 1917; Munz 1974). Historical maps were examined to locate landmarks cited in voucher collections but not present on current maps. These historical maps consisted of a United States Coast and Geodetic Survey in 1876 (Grossinger et al. 2011) and a vegetation mapping survey of the Redondo 15-minute quadrangle by Jensen (1933). These maps were overlaid on current topography using Geographic Information System software to verify locations of historical landmarks relative to the study area. Reports of archaeological surveys (Altschul et al. 1992, 2003) were reviewed for historical land alterations potentially affecting the flora.

All plant taxa reported from the study area are listed in Table 1. This table is necessarily abbreviated for presentation here. The entire database, including details such as accession numbers and references for each observation or collection, can be provided upon request. Only taxa indigenous or naturalized in the study area were included in this table in order to make the list more meaningful for analysis, restoration and management. In other words, non-invasive, non-native ornamental taxa known to be confined to existing or abandoned landscapes were omitted. A total of 407 taxa are shown in Table 1, of which about 40 percent (165 taxa) are not native to California. Changes in taxonomy over time, especially below the species level, have a minor effect on these statistics.

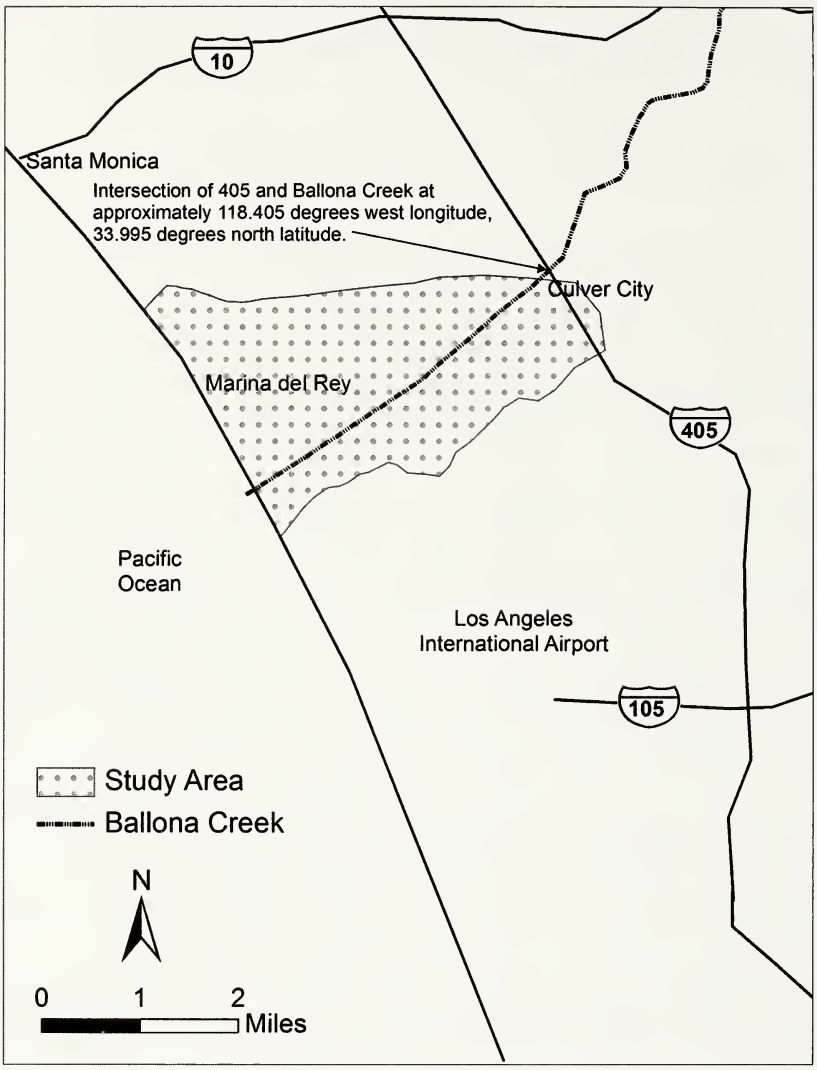

Fig. 1. Study Area Location.

Out of the 242 native taxa listed, about 26 percent (62 species) have not been observed or collected since the 1930s when there were major hydrological alterations of the area for flood control and farming. One of these historical species, Ballona cinquefoil (*Potentilla multijuga*), is believed to have been endemic to Ballona but extirpated sometime after its last collection in 1890 by H.E. Hasse from a "brackish area in coastal sage scrub".

Human impacts in the study area over the past two centuries have been documented extensively by others (Dark et al. 2011; Grossinger et al. 2011), so it is important to recognize that historical botanical collections from the study area do not represent pristine (pre-human disturbance) conditions or a complete flora of the region. A survey map of the wetlands was not published until 1876, which is 57 years after cattle herds were pastured in the Ballona Creek drainage beginning around 1819 (Altschul et al., 1992 p. 56). After 1819, the earliest known botanical collections from Ballona were by S.B. Parish 63 years later, in 1882.

Thus, given at least two centuries of land alteration in the region, it is not surprising that a substantial portion of the flora is not native. The proportion of non-native flora is high when compared to the proportion of 17% non-native taxa in California as a whole[1], and especially high considering the small size of the study area (1,824 ha) relative to the geographic extent of California (42,476 ha).

Most of the non-native flora has established in the absence of systematic efforts at restoring conditions suitable for sustaining native species in a heavily urbanized watershed, but not all of the invaders have been equally successful. One of the first records of non-native species is of fennel (*Foeniculum vulgare*), collected by Abrams in 1902, yet this species has not invaded the wetlands as extensively as a relative newcomer, pampas grass (*Cortaderia selloana*). There are no historic collections of *Cortaderia* from the study area and its occurrence at Ballona was unremarked until it was reported by Clark (1979).

Coastal estuarine and saltmarsh taxa are noticeably rare in the historical collections. Most of the historic flora is composed of species associated with upland, freshwater or brackish habitats. While there could be various reasons for this, the high proportion of non-estuarine taxa in historical collections is consistent with documentation by Dark et al. (2011) of springs and seasonal ponds that were prevalent historically but no longer exist. One example of this freshwater flora is giant horsetail (*Equisetum telmateia*), collected by Abrams in 1901 from Ballona Creek while it was still a meandering, natural stream. Another example is Oregon ash (*Fraxinus latifolia*) collected by Ewan in 1932 along Ballona Creek in the area of what is now Culver City. This is the only native tree represented in the historic flora.

Examination of the plant list also reveals interesting inconsistencies in the taxonomic records. For example, *Senecio californicus* was collected by Abrams in 1901, but later collectors (Gustafson 1981; Henrickson 1991) identified only *Senecio vulgaris*, a non-native species. This may be a simple misidentification, but alternatively could be an example of niche displacement of a native *Senecio* by an exotic species.

Lastly, determination of which species are truly "native" to the study area is complicated by changes in taxonomy (e.g., "lumping" vs. "splitting" varieties and subspecies), misidentifications, and intentional introduction of taxa for "restoration" without documentation of variety or seed origin. A species of pincushion (*Chaenactis glabriuscula*), an annual herb associated with sandy soils, has been reported several times since it was first collected in 1901. This taxon persists into the current period, but tracing its history of occurrence is complicated by taxonomic re-classifications of some historical collections, and "restoration" efforts that distributed *C. glabriuscula* seeds of unspecified variety and unknown origin. Currently, a variety considered rare by the California Native Plant Society and identified as *C. g.* var. *orcuttiana* persists in dunes that are subject to ongoing restoration efforts, but it is not clear whether this variety is indigenous, intentionally planted, or some combination of both. Some voucher specimens from the study area are classified as the more common variety, *C. g.* var. *glabriuscula*, and deserve further study.

Historical maps show "marsh" but are silent on the issue of what proportion of the wetlands consisted of freshwater vs. saltwater or brackish marsh. However, botanical records show that the study area was occupied by a highly diverse ecosystem. The area encompassed not just wetlands, but a wide variety of other habitat types including dunes, freshwater marshes, seasonal ponds, and riparian communities. Taxonomic inconsistencies in the botanical record introduce some margin of error in calculating species richness, but this is largely of academic interest. Habitat restoration in the study area offers a unique opportunity to reverse a decades-old trend

[1] Calculated from Baldwin et al. (2012), p. 1521.

of exotic invasion at the expense of native diversity, while recognizing that significant alterations of the watershed render it impossible to fully restore the historic flora. This study provides a starting point for enhancing function and diversity of the Ballona Wetlands.

Table 1. Checklist of the Flora of the Ballona Wetlands and Environs.

FERNS		Reference	Earliest Collection
Equisetaceae	**Horsetail Family**		
Equisetum telmateia Ehrh. ssp. *braunii* (J.Milde) Hauke	giant horsetail	DS, POM	1901
MAGNOLIDS			
Lauraceae	**Laurel Family**		
Umbellularia californica (Hook. & Arn.) Nutt.	California bay	FWM	R
Saururaceae	**Lizard's-Tail Family**		
Anemopsis californica (Nutt.) Hook. & Arn.	yerba mansa	POM, RSA,UC	1902
EUDICOTS			
Adoxaceae	**Muskroot Family**		
Sambucus nigra L. ssp. *caerulea* (Raf.) Bolli	blue elderberry	Henrickson 1991, FWM	R
Aizoaceae	**Iceplant Family**		
Aptenia cordifolia (L.f.) Schwantes*	baby sun rose	RSA	1981
Carpobrotus edulis (L.) N.E. Br.*	freeway iceplant	RSA	1980
Delosperma litorale (Kensit) L. Bolus*	ice plant	RSA	1981
Malephora crocea (Jacq.) Schwantes*	coppery mesembryanthemum	RSA	1981
Mesembryanthemum crystallinum L.*	common iceplant	Henrickson 1991	R
Mesembryanthemum nodiflorum L.*	slender-leaved iceplant	RSA	1980
Sesuvium verrucosum Raf.	western sea-purslane	UC	1902
Tetragonia tetragonioides (Pall.) Kuntze*	New Zealand spinach	RSA	1981
Amaranthaceae	**Amaranth Family**		
Amaranthus albus L.*	tumbleweed	RSA	1930
Amaranthus blitoides S. Watson	procumbent pigweed	RSA	1980
Amaranthus californicus (Moq.) S. Watson	Californian amaranth	Gustafson 1981	R
Amaranthus deflexus L.*	large fruited amaranth	RSA	1981
Amaranthus tuberculatus (Moq.) J.D. Sauer var. *rudis* (J.D. Sauer) Costea & Tardif*	common waterhemp	Henrickson 1991	R
Anacardeaceae	**Sumac Family**		
Malosma laurina (Nutt.) Abrams	laurel sumac	POM	1980
Rhus integrifolia (Nutt.) Rothr.	lemonade berry	Gustafson 1981	R
Rhus ovata S. Watson	sugar bush	RSA	1981
Schinus molle L.*	pepper tree	RSA	1980
Schinus terebinthifolius Raddi*	Brazilian pepper tree	Henrickson 1991	R
Apiaceae	**Carrot Family**		
Apium graveolens L.*	celery	RSA	1902
Conium maculatum L.*	poison hemlock	RSA	1981
Cyclospermum leptophyllum (Pers.) Britton & P. Wilson*	marsh parsley	RSA	1981
Foeniculum vulgare Mill.*	fennel	POM,RSA,UC	1902
Oenanthe sarmentosa DC.	water parsley	POM, UC	1902

Asterisk (*) indicates taxon not native to California. Grey background indicates a native taxon known only from historical (pre-1940) collections or reports. References: For herbarium specimens, the following acronyms from the Consortium of California Herbaria are used: CAS (California Academy of Sciences); CDA (California Department of Food and Agriculture); DS (Dudley Herbarium in CAS); JEPS (Jepson Herbarium, UC Berkeley); NY (New York Botanical Garden); POM (Pomona Herbarium in the Rancho Santa Ana Botanic Garden); RSA (Rancho Santa Ana Botanic Garden); SFV (California State University Northridge); UC (University Herbarium, UC Berkeley); UCD (UC Davis); UCR (UC Riverside). Where an author and year are cited, the taxon was reported but no voucher specimens could be located. "FWM" refers to a taxon that was observed by this author as having been planted at the constructed Ballona Freshwater Marsh but no records or reports of historical occurrence at Ballona were found. Earliest Collection: year of oldest voucher specimen is given. "R" means reported with no record of collection.

Table 1. Continued.

Apocynaceae	**Dogbane Family**		
Asclepias fascicularis Decne.	narrow-leaf milkweed	RSA	1930
Asteraceae	**Sunflower Family**		
Acroptilon repens (L.) DC.*	Russian knapweed	POM	1980
Amblyopappus pusillus Hook. & Arn.	dwarf coastweed	DS	1901
Ambrosia acanthicarpa Hook.	annual bursage	RSA	1980
Ambrosia chamissonis (Less.) Greene	beach bur-sage	DS,POM,RSA	1899
Ambrosia psilostachya DC.	western ragweed	DS,POM,UC,RSA	1902
Anthemis cotula L.*	mayweed	DS	1901
Artemisia californica Less.	California sagebrush	DS,RSA,UC	1902
Artemisia douglasiana Besser	mugwort	DS,POM,RSA	1901
Artemisia dracunculus L.	tarragon	DS,RSA,UC	1902
Baccharis glutinosa Pers.	marsh baccharis	DS,POM	1903
Baccharis pilularis DC.	coyote brush	POM	1980
Baccharis salicifolia (Ruiz & Pav.) Pers.	mulefat	POM,UC	1907
Bidens laevis (L.) Britton et al.	bur-marigold	DS,UC	1902
Brickellia californica (Torr. & A. Gray) A. Gray	California brickellbush	Henrickson 1991	R
Centaurea melitensis L.*	tocalote	POM	1980
Centromadia parryi (Greene) Greene ssp. *australis* (D.D. Keck) B.G. Baldwin	southern tarplant	JEPS,POM,RSA,UC	1890
Chaenactis glabriuscula DC. var. *orcuttiana* (Greene) H.M. Hall	Orcutt's pincushion	POM,RSA	1980
Chondrilla juncea L.*	skeleton weed	POM	1981
Cichorium intybus L.*	chicory	POM	1980
Cirsium vulgare (Savi) Ten.*	bull thistle	Gustafson 1981, Henrickson 1991	R
Coreothrogyne filaginifolia (Hook. & Arn.) Nutt.	California-aster	DS,POM	1899
Cotula australis (Spreng.) Hook. f.*	Australian cotula	Gustafson 1981, Henrickson 1991	R
Cotula coronopifolia L.*	brass-buttons	Gustafson 1981, Henrickson 1991	R
Deinandra fasciculata (DC.) Greene	clustered tarplant	POM	1980
Deinandra paniculata (A. Gray) Davidson & Moxley	paniculate tarplant	Henrickson 1991	R
Dimorphotheca fruticosa (L.) DC.*	trailing African daisy	Gustafson 1981, Henrickson 1991	R
Encelia californica Nutt.	California brittlebush	DS	1899
Ericameria ericoides (Less.) Jeps.	California goldenbush	POM	1981
Ericameria pinifolia (A. Gray) H.M. Hall	pine-bush	Henrickson 1991	R
Erigeron bonariensis L.*	flax-leaved horseweed	Gustafson 1981, Henrickson 1991	R
Erigeron canadensis L.	horseweed	POM	1980
Euryops pectinatus (L.) Cass.*	gray-leaf euryops	Henrickson 1991	R
Euthamia occidentalis Nutt.	western goldenrod	RSA,UC	1902
Gazania linearis (Thunb.) Druce*	treasure flower, African daisy	Henrickson 1991	R
Glebionis coronaria (L.) Spach*	garland or crown daisy	UCR	1996
Grindelia camporum Greene	common gumplant	POM	1980
Hedypnois cretica (L.) Dum.-Cours.*	Crete weed	POM	1981
Helianthus annuus L.	common sunflower	POM	1980
Helminthotheca echioides (L.) Holub*	bristly ox-tongue	RSA	1980
Heterotheca grandiflora Nutt.	telegraph weed	POM	1980

Table 1. Continued.

Hypochaeris glabra L.*	smooth cat's ear	Henrickson 1991	R
Isocoma menziesii (Hook. & Arn.)	coastal goldenbush	FWM	R
Iva axillaris Pursh	poverty weed	FWM	R
Jaumea carnosa (Less.) A. Gray	fleshy jaumea, marsh jaumea	POM,UC	1899
Lactuca serriola L.*	prickly lettuce	POM	1902
Lactuca virosa L.*	bitter lettuce	Henrickson 1991	R
Laennecia coulteri (A. Gray) G.L. Nesom	Coulter's horseweed	POM	1980
Lasthenia californica Lindl.	California goldfields	POM,RSA	1901
Lasthenia coronaria (Nutt.) Ornduff	crowned or royal goldfields	JEPS,POM	1901
Lasthenia glabrata Lindl. ssp. *coulteri* (A. Gray) Ornduff	Coulter's goldfields	POM	1903
Logfia filaginoides (Hook. & Arn.) Morefield	California cottonrose	POM	1901
Malacothrix saxatilis (Nutt.) Torrey & A. Gray	cliff aster	Gustafson 1981, Henrickson 1991	R
Matricaria discoidea DC.*	pineapple weed	POM	1981
Pluchea odorata (L.) Cass. var. *odorata*	saltmarsh fleabane	UC	1902
Pseudognaphalium bioletti Anderb.	two-color rabbit-tobacco	POM	1901
Pseudognaphalium californicum (DC.) Anderb.	ladies' tobacco	POM,UCR	1981
Pseudognaphalium canescens (DC.) Anderb.	cudweed	POM	1981
Pseudognaphalium microcephalum (Nutt.) Anderb.	Wright's cudweed	POM,UC	1902
Pseudognaphalium ramosissimum (Nutt.) Anderb.	pink cudweed	POM	1981
Pseudognaphalium stramineum (Kunth) Anderb.	cottonbatting plant	POM	1981
Senecio californicus DC.	California ragwort	POM	1901
Senecio vulgaris L.*	common groundsel	RSA	1930
Silybum marianum (L.) Gaertn.*	milk thistle	RSA	1981
Solidago velutina DC. ssp. *californica* (Nutt.) Semple	California goldenrod	Henrickson 1991	R
Sonchus asper (L.) Hill*	prickly sow thistle	RSA	1981
Sonchus oleraceus L.*	common sow thistle	RSA	1981
Stephanomeria diegensis Gottlieb	wreathplant	RSA	1980
Stephanomeria exigua Nutt.	small wirelettuce	Gustafson 1981	R
Stephanomeria virgata Benth.	twiggy wreath plant	RSA	1981
Symphyotrichum subulatum (Michx.) G.L. Nesom	annual saltmarsh aster	POM,UC	1901
Taraxacum officinale F.H. Wigg.*	common dandelion	Henrickson 1991	R
Tragopogon porrifolius L.*	purple salsify	UC	1897
Xanthium spinosum L.	spiny cocklebur	RSA	1981
Xanthium strumarium L.	cocklebur	UC	1902
Betulaceae	**Birch Family**		
Alnus rhombifolia Nutt.	white alder	FWM	R
Boraginaceae	**Borage Family**		
Amsinkia intermedia Fisch. & C.A. Mey	common fiddleneck	POM	1901
Amsinkia spectabilis Fisch. & C.A. Mey	seaside amsinkia	RSA	1951
Cryptantha clevelandii Greene	cryptantha	UCR	2011
Cryptantha clevelandii Greene var. *florosa* I.M. Johnst.	coastal cryptantha	POM	1901
Cryptantha intermedia (A. Gray) Greene	common cryptantha	POM	1901
Cryptantha microstachys (A.Gray) Greene	Tejon cryptantha	POM	1901
Heliotropium curassavicum L. var. *oculatum* (A. Heller) Tidestr.	seaside heliotrope	POM	1930
Phacelia parryi Torr.	Parry's phacelia	Henrickson 1991	R
Phacelia ramosissima Lehm.	branching phacelia	POM,RSA	1901

Table 1. Continued.

Brassicaceae	**Mustard Family**		
Brassica nigra (L.) W.D.J. Koch*	black mustard	Gustafson 1981, Henrickson 1991	R
Brassica rapa L.*	field mustard	RSA	1930
Cakile maritima Scop.*	sea-rocket	Gustafson 1981, Henrickson 1991	R
Caulanthus lasiophyllus (Hook. & Arn.) Payson	California mustard	DS	1899
Descurainia pinnata (Walter) Britton ssp. *brachycarpa* (Richardson) Detling	tansy mustard	DS	1901
Descurainia pinnata (Walter) Britton ssp. *menziesii* (D.C.) Detling	Menzies' tansy mustard	POM	1901
Erysimum suffrutescens (Abrams) Rossbach	suffrutescent wallflower	DS,POM,RSA	1901
Hirschfeldia incana (L.) Lagr.-Fossat*	summer mustard	Gustafson 1981, Henrickson 1991	R
Lepidium didymum L.*	lesser swine cress	Gustafson 1981, Henrickson 1991	R
Lepidium lasiocarpum Nutt.	shaggyfruit pepperweed	DS,POM	1901
Lepidium latipes Hook.	dwarf peppergrass	DS	1904
Lepidium latifolium L.*	perennial pepperweed	Henrickson 1991	R
Lepidium nitidum Nutt.	peppergrass	RSA	1954
Lepidium pinnatifidum Ledeb.*	featherleaf pepperweed	RSA	1981
Lepidium virginicum L. ssp. *menziesii* (DC.) Thell.	wild peppergrass	RSA	1930
Lobularia maritima (L.) Desv.*	sweet alyssum	Gustafson 1981, Henrickson 1991	R
Raphanus sativus L.*	radish	UCR	1996
Sinapis alba L.*	white mustard	Gustafson 1981, Henrickson 1991	R
Sisymbrium altissimum L.*	tumble mustard	Henrickson 1991	R
Sisymbrium irio L.*	London rocket	Gustafson 1981, Henrickson 1991	R
Tropidocarpum gracile Hook.	slender keel fruit	UC	1897
Cactaceae	**Cactus Family**		
Opuntia littoralis (Engelm.) Cockerell	coast prickly-pear	Henrickson 1991	R
Caryophyllaceae	**Pink Family**		
Polycarpon depressum Nutt.	California allseed	POM	1901
Polycarpon tetraphyllum (L.) L. var. *tetraphyllum**	four-leaved all seed	RSA,UCR	1981
Silene gallica L.*	small-flower catchfly	RSA,UCR	1980
Spergula arvenis L.*	stickwort, startwort	RSA	1981
Spergularia bocconi (Scheele) Graebn.*	Boccone's sand-spurrey	Henrickson 1991	R
Spergularia macrotheca (Cham. & Schltdl.) Heynh.	sticky sand-spurrey	POM,RSA	1901
Spergularia marina (L.) Besser	saltmarsh sand-spurrey	CDA,POM	1901
Spergularia villosa (Pers.) Cambess.*	hairy sand-spurrey	Henrickson 1991	R
Chenopodiaceae	**Goosefoot Family**		
Arthrocnemum subterminale (Parish) Standl	pickleweed	POM,RSA,UC	1902
Atriplex argentea Nutt. var. *expansa* (S. Watson) S.L. Welsh & Reveal	silverscale	UC	1902
Atriplex californica Moq.	California orach	RSA	1981
Atriplex lentiformis (Torr.) S. Watson	big saltbush	RSA	1981
Atriplex lentiformis (Torr.) S. Watson subsp. *lentiformis*	big saltbush	UC	1902
Atriplex leucophylla (Moq.) D. Dietr	beach saltbush	RSA,UC	1899
Atriplex nummularia Lindl.*	bluegreen saltbush	Henrickson 1991	R

Table 1. Continued.

Atriplex patula L.	spear orach	RSA	1980
Atriplex prostrata DC.*	fat-hen	RSA	1980
Atriplex rosea L.*	tumbling orach	RSA,UC	1902
Atriplex semibaccata R. Br.*	Australian saltbush	RSA,UC	1902
Atriplex suberecta I. Verd.*	sprawling saltbush	RSA	1981
Bassia hyssopifolia (Pall.) Kuntze*	five horn bassia	RSA	1980
Beta vulgaris L.*	common beet	CDA,POM,RSA,UC	1902
Chenopodium album L.*	lamb's quarters	RSA	1981
Chenopodium berlandieri Moq.	pitseed goosefoot	RSA	1980
Chenopodium murale L.*	nettle leaf goosefoot	CDA,RSA	1930
Dysphania ambrosioides (L.) Mosyakin & Clemants*	Mexican tea	RSA,UC	1902
Dysphania pumilio (R.Br.) Mosyakin & Clemants*	Tasmanian goosefoot	Henrickson 1991	R
Salicornia pacifica Standl	pickleweed	RSA,UC	1902
Salsola tragus L.*	Russian thistle	RSA	1980
Suaeda calceoliformis (Hook.) Moq	horned seablite	Gustafson 1981, Henrickson 1991	R
Suaeda californica S. Watson	California seablite	Gustafson 1981	R
Suaeda taxifolia (Standl.) Standl.	woolly sea-blite	POM,RSA	1901
Cleomaceae	**Spiderflower Family**		
Peritoma arborea (Nutt.) H.H. Iltis	bladderpod	DS,POM	1899
Convolvulaceae	**Morning-Glory Family**		
Calystegia macrostegia (Greene) Brummit ssp. *cyclostegia* (House) Brummit	coast morning glory	RSA	1981
Calystegia soldanella (L.) R.Br.	beach morning glory	SFV	1994
Convolvulus arvensis L.*	orchard morning glory	RSA	1930
Cressa truxillensis Kunth	alkali weed	POM,RSA,UCR	1901
Cuscuta californica Hook. & Arn.	chaparral dodder	RSA	1981
Cuscuta indecora Choisy var. *indecora*	large-seeded dodder	Henrickson 1991	R
Cuscuta campestris Yunck	field dodder	RSA	1981
Cuscuta salina Engelm	salt dodder	RSA,UC	1902
Dichondra occidentalis House	western dichondra	Henrickson 1991	R
Crassulaceae	**Stonecrop Family**		
Crassula connata (Ruiz & Pav.) A. Berger	pygmy-weed	POM,RSA	1901
Dudleya lanceolata (Nutt.) Britton & Rose	lance leaf liveforever	POM	1901
Cucurbitaceae	**Gourd Family**		
Citrullus lanatus (Thunb.) Matsum. & Nakai var. *citroides* (L.H. Bailey) Mansf.*	wild watermelon	RSA	1981
Cucurbita foetidissima Kunth.	calabazilla, buffalo gourd	RSA	1980
Euphorbiaceae	**Spurge Family**		
Chamaesyce albomarginata (Torr. & A. Gray) Small	rattlesnake weed	RSA	1981
Chamaesyce maculata (L.) Small*	spotted spurge	RSA	1981
Chamaesyce polycarpa (Benth.) Millsp.	small seeded spurge	RSA	1981
Chamaesyce serpens (Kunth) Small*	creeping spurge	RSA	1980
Croton californicus Mull. Arg.	California croton	POM,RSA	1899
Croton setigerus Hook.	turkey-mullein	RSA	1930
Euphorbia peplus L.*	petty spurge	RSA	1981
Euphorbia terracina L.*	carnation weed	RSA,UCR	1996
Euphorbia virgata Waldst. & Kit.*	leafy spurge	Henrickson 1991	R
Ricinus communis L.*	castor bean	RSA,UCR	1981

Table 1. Continued.

Fabaceae	**Legume Family**		
Acacia baileyana F. Muell.*	Cootamundra wattle	RSA	1981
Acacia cyclops G. Don*	western coastal wattle	RSA,UCR	1996
Acacia dealbata Link*	silver wattle	Gustafson 1981, Henrickson 1991	R
Acacia longifolia (Andrews) Willd.*	Sydney golden wattle	Henrickson 1991	R
Acacia neriifolia A. Cunn. ex Benth*	black wattle	Henrickson 1991	R
Acmispon americanus (Nutt.) Rydb. var. *americanus*	American bird's foot trefoil	RSA	1980
Acmispon glaber (Vogel) Brouillet	deerweed, California broom	RSA	1980
Acmispon heermannii (Durand & Hilg.) Brouillet	Heermann's lotus	UC	1902
Acmispon strigosus (Nutt.) Brouillet	strigos lotus	RSA	1981
Albizia distachya J.F. Macbr.*	Australian albizia	Gustafson 1981, Henrickson 1991	R
Albizia lophantha (Willd.) Benth.*	plume acacia	CDA,RSA	1981
Astragalus pycnostachyus A. Gray var. *lanosissimus* (Rydb.) Munz & McBurney	Ventura marsh milk vetch	NY,POM,RSA,UC	1882
Astragalus tener A. Gray var. *titi* (Eastw.) Barneby	coastal dunes milk vetch	DS	1891
Astragalus trichopodus (Nutt.) A. Gray	Santa Barbara milkvetch	Henrickson 1991	R
Astragalus trichopodus (Nutt.) A. Gray var. *lonchus* (M.E. Jones) Barneby	Santa Barbara milkvetch	DS	1901
Hoffmanseggia glauca (Ortega) Eifert	pig-nut, hog potato	Henrickson 1991	R
Lupinus bicolor Lindl.	miniature lupine	POM	1981
Lupinus chamissonis Eschsch.	beach blue lupine, dune lupine	POM,RSA	1917
Lupinus excubitus M.E. Jones var. *hallii*	grape soda lupine	RSA,UCR	1980
Lupinus longifolius (S. Watson) Abrams	longleaf bush lupine	POM	1901
Lupinus succulentus K. Koch	arroyo lupine	RSA	1981
Lupinus truncatus Nutt.	blunt leaved lupine	POM,RSA	1899
Medicago polymorpha L.*	California burclover	POM	1981
Melilotus albus Medik.*	white sweetclover	POM	1980
Melilotus indicus (L.) All.*	sourclover	POM,UCD,UCR	1978
Phaseolus limensis Macfad.*	lima bean	POM	1981
Spartium junceum L.*	Spanish broom	Henrickson 1991	R
Frankeniaceae	**Frankenia Family**		
*Frankenia salina (*Molina) I.M. Johnst.	alkali heath	POM,RSA	1917
Geraniaceae	**Geranium Family**		
Erodium botrys (Cav.) Bertol.*	broad leaf filaree	RSA,UCR	1981
Erodium cicutarium (L.) Aiton*	redstem filaree	Gustafson 1981, Henrickson 1991	R
Erodium moschatum (L.) Aiton*	greenstem filaree	UCR	1996
Grossulariaceae	**Gooseberry Family**		
Ribes malvaceum Sm.	chaparral currant	RSA	1981
Hamamelidaceae	**Witch-Hazel Family**		
Liquidambar styraciflua L.*	sweet-gum	Henrickson 1991	R
Juglandaceae	**Walnut Family**		
Juglans californica S. Watson	southern California black walnut	FWM	R
Juglans regia L.*	English walnut	Henrickson 1991	R

Table 1. Continued.

Lamiaceae	**Mint Family**		
Lycopus americanus W.P.C. Barton	bugleweed	UC	1902
Marrubium vulgare L.*	horehound	RSA	1981
Mentha x *piperita* L.*	peppermint	UC	1902
Mentha x smithiana R.A. Graham*	redstem mint	POM	1902
Salvia apiana Jeps.	white sage	FWM	R
Salvia carduacea Benth.	thistle sage	POM,UCR	1901
Salvia columbariae Benth.	chia	POM,UCR	1901
Salvia leucophylla Greene	purple sage	FWM	R
Stachys ajugoides Benth.	hedge-nettle	POM,UC	1917
Stachys albens A. Gray	white hedge-nettle	POM,RSA,UC	1902
Stachys bergii G.A. Mulligan & D.B.Munro	Berg's hedge-nettle	UC	1932
Lythraceae	**Loosestrife Family**		
Lythrum californicum Torr. & A. Gray	California loosestrife	POM,RSA,UC	1902
Lythrum hyssopifolia L.*	hyssop loosestrife	RSA,UCR	1980
Malvaceae	**Mallow Family**		
Malacothamnus fasciculatus (Torr. & A. Gray) Greene	chaparral mallow	RSA	1981
Malva nicaeensis All.*	bull mallow	POM	1902
Malva parviflora L.*	cheeseweed	RSA,UC	1932
Malva pseudolavatera Webb & Berthel.*	Cretan mallow	RSA,UCR	1981
Malvella leprosa (Ortega) Krapov.	alkali-mallow	POM,RSA,UCR	1917
Montiaceae	**Miner's Lettuce Family**		
Calandrinia ciliata (Ruiz & Pav.) DC.	red maids	UC	1897
Myrsinaceae	**Myrsine Family**		
Anagallis arvensis L.*	scarlet pimpernel	RSA	1980
Myrtaceae	**Myrtle Family**		
Eucalyptus camaldulensis Dehnh.*	red gum, river red gum	RSA	1981
Eucalyptus globulus Labill.*	blue gum	Henrickson 1991	R
Eucalyptus tereticornis Sm.*	forest red gum	Gustafson 1981	R
Eucalyptus viminalis Labill.*	manna gum	RSA	1981
Nyctaginaceae	**Four O' Clock Family**		
Abronia maritima S. Watson	red sand-verbena	POM	1901
Abronia umbellata Lam.	beach sand-verbena	POM,RSA	1901
Oleaceae	**Olive Family**		
Fraxinus latifolia Benth.	Oregon ash	UC	1932
Fraxinus velutina Torr.	velvet ash	RSA	1981
Onagraceae	**Evening-Primrose Family**		
Camissoniopsis bistorta (Torr. & A. Gray) W.L. Wagner & Hoch	California sun cup	POM,RSA,UC	1897
Camissoniopsis cheiranthifolia (Spreng.) W.L. Wagner & Hoch ssp. *suffruticosa*	beach evening-primrose	POM,RSA,UCD	1901
Camissoniopsis lewisii (P.H. Raven) W.L. Wagner & Hoch	Lewis' evening primrose	POM	1899
Camissoniopsis micrantha (Spreng.) W.L. Wagner & Hoch	miniature suncup	RSA	1981
Epilobium campestre (Jeps.) Hoch & W.L. Wagner	smooth boisduvalia	POM	1901
Epilobium ciliatum Raf.	slender willow herb	RSA	1930
Oenothera elata Kunth.	evening primrose	RSA	1981

Table 1. Continued.

Orobanchaeae	**Broomrape Family**		
Castilleja exserta (A. Heller) T.I. Chuang & Heckard ssp. *exserta*	purple owl's-clover	POM,RSA	1901
Chloropyron maritimum (Benth.) A. Heller ssp. *maritimum*[h]	salt marsh bird's beak	DS,POM	1901
Oxalidaceae	**Oxalis Family**		
Oxalis pilosa Nutt.	hairy wood sorrel	Henrickson 1991	R
Oxalis pes-caprae L.*	Bermuda buttercup	Gustafson 1981, Henrickson 1991	R
Papaveraceae	**Poppy Family**		
Eschscholzia californica Cham.	California poppy	Henrickson 1991	R
Papaver heterophyllum (Benth.) Greene	wind poppy	RSA	1899
Plantaginaceae	**Plantain Family**		
Antirrhinum coulterianum A. DC.	Coulter's snapdragon	POM	1911
Antirrhinum nuttallianum A. DC. ssp. *nuttalianum*	Nuttall's snapdragon	UC	1902
Plantago erecta E. Morris	California plantain	POM	1899
Plantago lanceolata L.*	English plantain	POM,RSA	1902
Plantago major L.*	common plantain	RSA	1980
Platanaceae	**Sycamore Family**		
Platanus racemosa Nutt.	western sycamore	FWM	R
Polygonaceae	**Buckwheat Family**		
Chorizanthe parryi Wats. var. *fernandina* (Wats.) Jeps.	San Fernando Valley spineflower	DS	1901
Eriogonum fasciculatum Benth.	California buckwheat	RSA	1981
Eriogonum fasciculatum Benth. var. *fasciculatum*	coastal California buckwheat	Gustafson 1981, Henrickson 1991	R
Eriogonum gracile Benth.	slender buckwheat	POM,RSA	1901
Eriogonum parvifolium Sm.	seacliff wild buckwheat	RSA,UC	1902
Lastarriaea coriacea (Goodman) Hoover	leather-spineflower	POM	1901
Mucronea californica Benth.	California spineflower	DS,POM	1899
Persicaria hydropiperoides (Michx.) Small	false waterpepper	POM,UC	1901
Persicaria lapathifolia (L.) Gray	willow weed	RSA	1930
Persicaria maculosa Gray*	lady's thumb	RSA	1980
Polygonum aviculare L.*	knotweed, knotgrass	CDA,RSA	1930
Rumex conglomeratus Murray*	clustered dock	RSA	1930
Rumex crispus L.*	curly dock	RSA	1930
Rumex fueginus Phil.	golden dock	POM,RSA	1902
Rumex salicifolius Weinm.	willow dock	RSA	1981
Ranunculaceae	**Buttercup Family**		
Clematis ligusticifolia Nutt.	western virgin's bower	RSA	1981
Delphinium parryi A. Gray	larkspur	DS	1901
Delphinium parryi A. Gray ssp. *maritimum* (Davidson) M. J. Warnock	maritime larkspur	DS	1901
Rosaceae	**Rose Family**		
Heteromeles arbutifolia (Lindl.) M. Roem.	toyon	Henrickson 1991	R
Horkelia cuneata Lindl. var. *sericea* A. Gray	Kellogg's horkelia	Abrams 1902	R
Potentilla anserina L. ssp. *pacifica* (Howell) Rousi	Pacific silverweed	POM,UC,UCR	1900
Potentilla multijuga Lehm.	Ballona cinquefoil	POM	1890
Pyracantha cf. *crenulata* (D. Don) M. Roem.*	Himalayan firethorn	Henrickson 1991	R
Rosa californica Cham. & Schltdl.	California rose	Henrickson 1991	R
Rubus ursinus Cham. & Schltdl.	California blackberry	FWM	R

Table 1. Continued.

Rubiaceae	**Madder Family**		
Galium angustifolium A. Gray	narrowly leaved bedstraw	POM	1980
Salicaceae	**Willow Family**		
Populus fremontii S. Watson ssp. *fremontii*	Fremont cottonwood	POM	1981
Salix exigua Nutt. var. *exigua*	narrow-leaved willow	FWM	R
Salix goodingii C.R. Ball	Gooding's black willow	FWM	R
Salix laevigata Bebb	red willow	DS,POM	1901
Salix lasiolepis Benth.	arroyo willow	DS,POM,UC	1932
Scrophulariaceae	**Figwort Family**		
Myoporum laetum G. Forst.*	myoporum	RSA	1981
Scrophularia californica Cham. & Schltdl.	California figwort	RSA	1930
Verbascum virgatum Stokes*	wand mullein	RSA	1981
Solanaceae	**Nightshade Family**		
Datura wrightii Regel	Jimson weed	RSA	1980
Lycium ferocissimum Miers*	African boxthorn	CDA,RSA	1978
Lycopersicum esculentum Mill.*	tomato	RSA	1981
Nicotiana clevelandii A. Gray	Cleveland's tobacco	POM,RSA	1901
Nicotiana glauca Graham*	tree tobacco	RSA	1980
Petunia parviflora Juss.	wild petunia	RSA	1981
Solanum americanum Miller	American black nightshade	RSA	1981
Solanum douglasii Dunal	Douglas' nightshade	POM,RSA,UCR	1901
Solanum nigrum L.*	black nightshade	Gustafson 1981, Henrickson 1991	R
Solanum physalifolium Rusby var. *nitidibaccatum* (Bitter) Edmonds*	nightshade	RSA	1981
Solanum xanti A. Gray	chaparral nightshade	Henrickson 1991	R
Tamariscaceae	**Tamarisk Family**		
Tamarix ramosissima Ledeb.*	saltcedar	Henrickson 1991	R
Ulmaceae	**Elm Family**		
Ulmus parvifolia Jacq.*	Chinese elm, lacebark elm	Henrickson 1991	R
Urticaceae	**Nettle Family**		
Urtica dioica L. ssp. *holosericea* (Nutt.) Thorne	hoary nettle	POM,RSA	1902
Urtica urens L.*	dwarf nettle	RSA	1981
Verbenaceae	**Vervain Family**		
Phyla lanceolata (Michx.) Greene	lance leaf lippia	POM,UC	1902
Verbena bracteata Lag. & Rodr.	bracted verbena	POM	1902
Verbena lasiostachys Link	western verbena	RSA	1981
Verbena lasiostachys Link var. *lasiostachys*	western vervain	RSA	1930
Zygophyllaceae	**Caltrop Family**		
Tribulus terrestris L.*	puncture vine	RSA	1980
MONOCOTS			
Agavaceae	**Century Plant Family**		
Hesperoyucca whipplei (Torr.) Trel.	chaparral yucca	FWM	R
Alismataceae	**Water-Plantain Family**		
Sagittaria montevidensis Cham. & Schltdl ssp. *calycina* (Engelm.)	arrowhead	RSA	1981
Amaryllidaceae	**Amaryllus Family**		
Narcissus tazetta L.*	paper white	RSA	1981

Table 1. Continued.

Araceae	**Arum Family**		
Lemna minuta Kunth	duckweed	RSA	1930
Arecaeae	**Palm Family**		
Phoenix canariensis Chabaud*	Canary Island palm	RSA	1981
Phoenix dactylifera L.*	date palm	MEC 2005	R
Washingtonia robusta H. Wendl.*	fan palm	Henrickson 1991	R
Cyperaceae	**Sedge Family**		
Bolboschoenus maritimus (L.) Palla	saltmarsh bulrush	DS,RSA	1904
Bolboschoenus maritimus (L.) Palla ssp. *paludosus* (A. Nelson) T. Koyama	saltmarsh bulrush	RSA,UCR	1981
Bolboschoenus robustus (Pursh) Sojak	seacoast bulrush	Gustafson 1981, Henrickson 1991	R
Carex praegracilis W. Boott	black creeper, freeway sedge	CAS,DS,POM	1889
Cyperus eragrostis Lam.	tall flatsedge	RSA,SD,UCR	1980
Cyperus esculentus L.	yellow nutgrass	RSA	1981
Cyperus involucratus Rottb.*	umbrella sedge	Gustafson 1981, Henrickson 1991	R
Eleocharis macrostachya Britton	creeping spike rush	RSA	1930
Eleocharis montevidensis Kunth	sand spikerush	DS,RSA	1904
Schoenoplectus americanus (Pers.) Schinz & R. Keller	Olney's three-square bulrush	DS,RSA	1900
Schoenoplectus californicus (C.A. Mey.) Sojak	southern bulrush	DS,RSA	1901
Iridaceae	**Iris Family**		
Iris pseudacorus L.*	horticultural iris	RSA	1981
Sisyrinchium bellum S. Watson	western blue-eyed-grass	FWM	R
Juncaceae	**Rush Family**		
Juncus acutus L.	spiny rush	DS	1901
Juncus balticus Willd. subsp. *ater* (Rydb.) Snogerup	Baltic rush	Gustafson 1981, Henrickson 1991	R
Juncus bufonius L.	toad rush	RSA	1981
Juncus mexicanus Willd.	Mexican rush	RSA	1981
Juncus textilis Buchenau	mat or basket rush	RSA	1930
Poaceae	**Grass Family**		
Agrostis stolonifera L.*	creeping bent	Gustafson 1981, Henrickson 1991	R
Arundo donax L.*	giant reed	RSA	1981
Avena barbata Link*	slender wild oat	Henrickson 1991	R
Avena fatua L.*	wild oat	RSA	1981
Brachypodium distachyon (L.) P. Beauv.*	false brome	Henrickson 1991	R
Bromus carinatus Hook. & Arn. var. *marginatus* (Steud.) Barkworth & Anderton	mountain brome	Gustafson 1981	R
Bromus catharticus Vahl var. *catharticus**	rescue grass	POM	1981
Bromus diandrus Roth*	ripgut grass	POM	1930
Bromus hordeaceus L.*	soft chess	POM	1981
Bromus madritensis L. ssp. *rubens* (L.) Husn.*	red brome	POM	1901
Cortaderia jubata (Lem.) Stapf*	purple pampas grass	Gustafson 1981, Henrickson 1991	R
Cortaderia selloana (Schult. & Schult. f.) Asch. & Graebn.*	Uruguayan pampas grass	RSA	1980
Cynodon dactylon (L.) Pers.*	Bermuda grass	RSA	1930
Digitaria sanguinalis (L.) Scop.*	hairy crab grass	POM	1981
Distichlis littoralis (Engelm.) H.L. Bell & Columbus	shore grass	Henrickson 1991	R
Distichlis spicata (L.) Greene	salt grass	UC	1902

Table 1. Continued.

Echinochloa crus-galli (L.) P. Beauv.*	barnyard grass	POM	1981
Ehrharta erecta Lam.*	panic veldt grass	POM,UCR	1981
Elymus condensatus J. Presl.	giant wild-rye	Henrickson 1991	R
Elymus glaucus Buckley	western wild-rye	POM	1901
Elymus trachycaulus (Link) Shinn. ssp. *trachycaulus*	slender wheatgrass	Abrams 1902	R
Elymus triticoides Buckley	beardless wild rye	POM	1901
Festuca arundinacea Schreb.*	tall fescue	Henrickson 1991	R
Festuca myuros L.*	rattail sixweeks grass	POM	1913
Festuca perennis (L.) Columbus & J.P. Sm.*	rye grass	POM,RSA,UCR	1902
Festuca tementula (L.) Columbus & J.P. Sm.*	Darnel ryegrass	POM	1901
Hainardia cylindrica (Willd.) Greuter*	barb grass	POM,UCD	1901
Hordeum brachyantherum Nevski	meadow barley	POM	1930
Hordeum murinum L. ssp. *leporinum* (Link) Arcang.*	hare barley	POM	1981
Hordeum intercedens Nevski	bobtail barley	POM	1901
Hordeum vulgare L.*	barley	Gustafson 1981, Henrickson 1991	R
Koelaria macrantha (Ledeb.) Schult.	June grass	POM	1901
Lamarckia aurea (L.) Moench*	goldentop	Henrickson 1991	R
Leptochloa fusca (L.) Kunth ssp. *uninervia* (J. Presl) N. Snow	Mexican sprangletop	POM	1981
Melica imperfecta Trin.	little California melica	POM	1901
Parapholis incurva (L.) C.E. Hubb.*	sickle grass	POM	1981
Paspalum dilatatum Poir.*	dallis grass	POM	1980
Pennisetum setaceum (Forssk.) Chiov.*	crimson fountain grass	Henrickson 1991	R
Phalaris minor Retz.*	Mediterranean canary grass	UC	1932
Phalaris paradoxa L.*	Hood canary grass	POM	1981
Poa annua L.*	annual blue grass	RSA	1981
Polypogon monspeliensis (L.) Desf.*	annual beard grass	Gustafson 1981, Henrickson 1991	R
Polypogon viridis (Gouan) Breistr.*	water beard grass	RSA	1930
Schismus barbatus (L.) Thell.*	Mediterranean grass	Gustafson 1981, Henrickson 1991	R
Setaria parviflora (Poir.) Kerguélen	knotroot bristle grass	RSA	1981
Sorghum halepense (L.) Pers.*	Johnson grass	UC	1902
Stenotaphrum secundatum (Walter) Kuntze*	Saint Augustine grass	RSA	1981
Stipa cernua Stebbins & Love	nodding needle grass	Henrickson 1991	R
Stipa lepida Hitchc.	foothill needle grass	FWM	R
Stipa miliacea (L.) Hoover var. *miliacea**	smilo grass	POM	1981
Stipa pulchra Hitchc.	purple needle grass	FWM	R
Ruppiaceae	**Ditch-Grass Family**		
Ruppia maritima L.	ditch-grass	RSA	1980
Themidaceae	**Brodiaea Family**		
Dichelostemma capitatum (Benth.) Alph. Wood	blue dicks	Henrickson 1991	R
Typhaceae	**Cattail Family**		
Sparganium erectum L. ssp. *stoloniferum* (Grabner) C. Cook & M.S. Nicholls	bur reed	RSA,UC	1902
Typha domingensis Pers.	southern cattail	RSA	1981
Typha latifolia L.	broad-leaved cattail	RSA	1980

Literature Cited

Abrams, L.A. 1902. Additions to the flora of Los Angeles County. please change to Bull. S. Calif. Acad. Sci., 1 (7): 87.

Abrams, L.A. 1917. Flora of Los Angeles and Vicinity. New Era Printing Company, Lancaster, Pennsylvania.

Altschul, J.H., J.A. Homburg, and R.S. Ciolek-Torrello. 1992. Life in the Ballona: Archaeological Investigations at the Admiralty Site (CA-LAN-47) and the Channel Gateway Site (CA-LAN-1596-H). Statistical Research, Inc. Technical Series No. 33.

Altschul, J.H., A.Q. Stoll, D.R. Grenda, and R. Ciolek-Torrello. 2003. At the Base of the Bluff: Archaeological Inventory and Evaluation along Lower Centinela Creek, Marina del Rey, California. Statistical Research, Inc. Playa Vista Monograph Series Test Excavation Report 4.

Baldwin, B.G., D.H. Goldman, D.J. Keil, R. Patterson, T.J. Rosatti, and D.H. Wilken, editors. 2012. The Jepson manual: vascular plants of California, second edition. University of California Press, Berkeley.

Clark, J. 1979. Ballona Vegetation Survey. Report dated May 10, 1979, prepared for The Conservation Foundation.

Dark, S., E.D. Stein, D. Bram, J. Monteferante, T. Longcore, R. Grossinger, and E. Beller. 2011. Historical Ecology of the Ballona Creek Watershed. Southern California Coastal Water Research Project Technical Report #671.

Grossinger, R.M., E.D. Stein, K.N. Cayce, R.A. Askevold, S. Dark, and A.A. Whipple. 2011. Historical Wetlands of the Southern California Coast: An Atlas of US Coast Survey T-Sheets, 1851-1889. San Francisco Estuary Institute Contribution # 586, Southern California Coastal Water Research Project Technical Report # 589. data download for T-Sheet #T1432b from caltsheets.org/socal/index.html.

Gustafson, R.J. 1981. The Vegetation of Ballona. Undated report prepared for Playa Vista.

Henrickson, J. 1991. Botanical Resources of Playa Vista. Report dated May 12, 1991, prepared for Playa Vista.

Jensen, S.A. 1933. Vegetation Map of the Redondo 15-Minute Quadrangle. Downloaded from http://vtm.berkeley.edu.

Johnston, K., 2011. The Ballona Wetlands Ecological Reserve Baseline Assessment Program 2009-2010 Final Report. Prepared for the California State Coastal Conservancy and California Department of Fish and Game. Issued November, 2011.

MEC Analytical Systems, 2005. 2004 Biological Study of Ballona Wetlands, Los Angeles County, California. Final Report, prepared for US Army Corps of Engineers Los Angeles District.

Munz, P.A. 1974. A Flora of Southern California. University of California Press, Berkeley, California.

Read, E. 1995. Sensitive Plant Surveys and Vegetation Update for Playa Vista. Report prepared for Impact Sciences, Inc.

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